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INTERPRETION OF SEDIMENT DATA 1966-1984 KENNEBECASIS RIVER NEW BRUNSWICK

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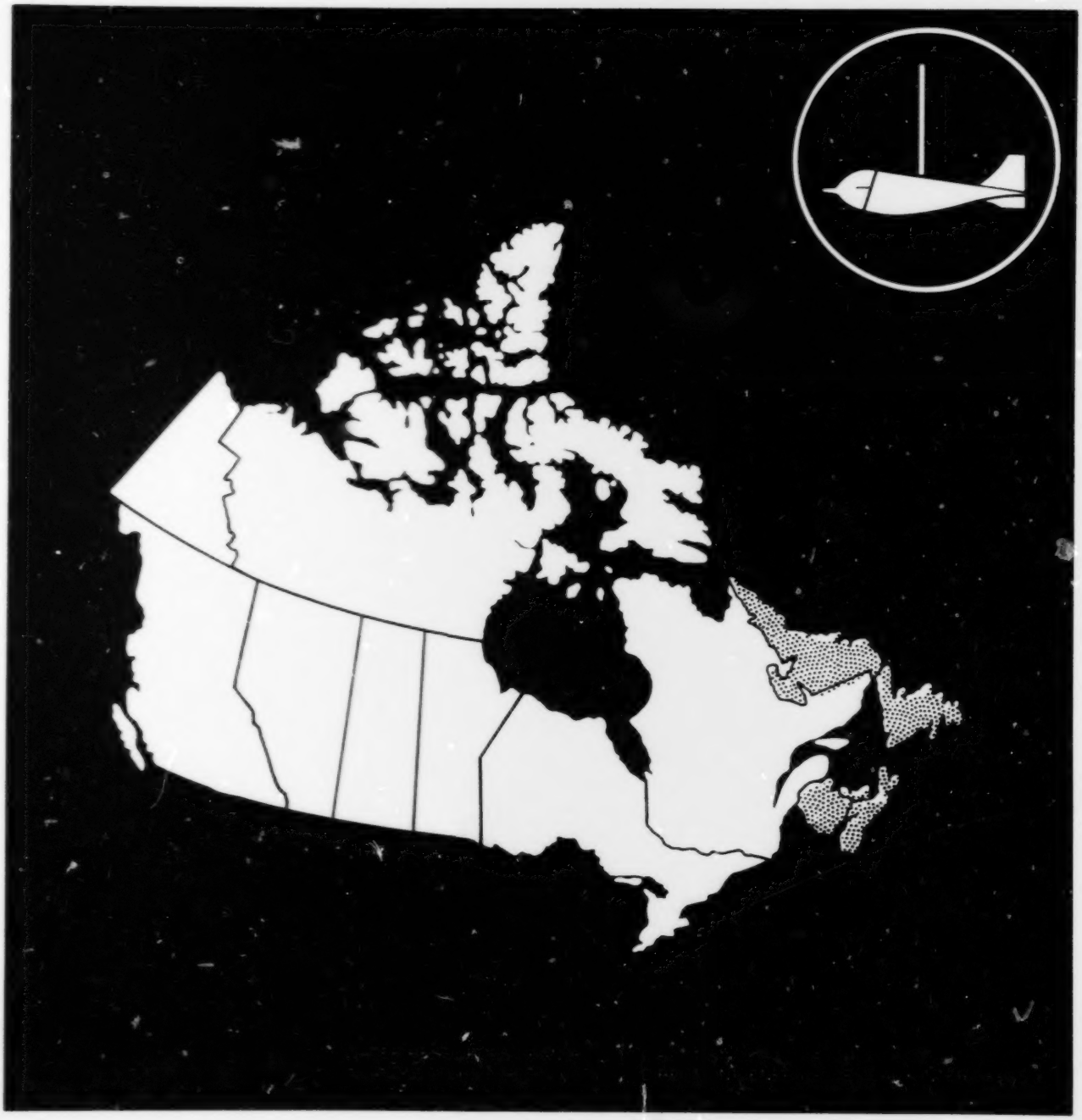

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The Malone Bridge (dated 1910) crosses the upper reaches of the Kennebecasis 1.5 km southwest of Upper Goshen. The arrow marks the addition of protective rock (to right) added to combat the bank erosion to the left. A new home is under construction in the background.

INTERPRETATION OF SEDIMENT DATA

1966 - 1984

KENNEBECASIS RIVER

NEW BRUNSWICK

IW/L-AR-WRB-87-129

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ABSTRACT

Sediment data have been collected at the hydrometric gauging station site, Kennebecasis River at Apohaqui, from 1966 to the present as part of the ongoing Water Resources Branch National Sediment Surveys Program. This report deals primarily with suspended sediment data collected during the period 1967 to 1984, inclusive, and presents the collected data in various tabular, graphical and statistical ways. It also contains a basin description and a section on land use and river sediments. The suspended sediment program, operated by the Water Survey of Canada Division, is evaluated and recommendations are presented. This material is intended for Federal/Provincial co-ordinators of water agreements, Water Survey of Canada staff and users of sediment data.

The analyses and interpretations of the sediment data are for the purpose of assessing if sufficient data exist for load determinations. The interpretation of the suspended sediment data set showed that our knowledge of mean characteristics of the sediment regime can improve only slightly; therefore, it is being recommended that the sediment station be discontinued.

RESUME

Des données sédimentologiques ont été prélevées à la station de relevés hydrométriques de la rivière Kennebecasis à Apohaqui à partir de 1966 jusqu'à présent. Ces prélèvements font partie du Programme national d'échantillonage sédimentologique de la Direction des ressources en eau.

Ce rapport traite principalement de données sur les sédiments en suspension collectionnées durant la période de 1967 à 1984 et les présente sous formes de tableaux, de graphiques et de statistiques. Le rapport comprend aussi une description du basin, une section sur l'utilisation du terrain, ainsi qu'une section sur les sédiments de rivière. Le rapport fait une évaluation du programme sur les sédiments en suspension de la Division des relevés hydrologiques du Canada et offre aussi des recommendations. Ce travail sera utile aux coordonateurs des ententes fédérales-provinciales sur l'eau, aux employés de la Division des relevés hydrologiques du Canada et aux usagers de données sédimentologiques.

Les analyses et les interprétations effectuées sur les données sédimentologiques ont permis d'évaluer la suffisance des données sur les sédiments en suspension pour en calculer le débit solide. Celles-ci ont montré que notre connaissance du régime sédimentologique en terme de production moyenne n'augmenterait pas sensiblement avec plus de données et qu'ainsi l'échantillonage peut être discontinué.

ACKNOWLEDGEMENT

Thanks are expressed to Dave Wilson of the Lands Division of the Water Planning and Management Branch of Inland Waters/Lands, Atlantic Region who accompanied the author on a tour of the Kennebecasis watershed. Mr. Wilson took most of the photographs of the sediment sources in the basin and he also prepared the section on "Land Use and River Sediments" found in this report.

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1.0 INTRODUCTION

1.1 Historical Perspective

Suspended sediment data have been collected on the Kennebecasis River at Apohaqui, New Brunswick, since July of 1966. Hydrometric data have been collected at this location since June of 1961. The sediment program was originally required in support of Federal/Provincial programs regarding sediment total loadings from the southern agricultural region of New Brunswick (Pol, 1976). The Water Survey of Canada Division of the Water Resources Branch of Environment Canada has the responsibility for collecting the sediment data.

Figure 1 shows the location of the Kennebecasis River Basin in New Brunswick. There are approximately 19 years of sediment data available for interpretation on this river.

1.2 Objectives

The objectives of the study are to:

1. Analyse and interpret the 1966 to 1984 sediment record for the purpose of assessing if sufficient data exist for load determinations.

2. Make recommendations as to whether or not data collection should be continued.

1.3 Report Format

This report is modelled on the existing series of sediment station analysis reports, issued by the Water Resources Branch, Environment Canada (Northwest Hydraulic Consultants Ltd., 1986).

2.0 BACKGROUND

2.1 Hydrometric Station Description

The Kennebecasis River at Apohaqui gauging station has been operated on a continuous basis since 1 June 1961; the data to 1970 have been reviewed. This station consists of a manometer system linked to an A-35 Stevens strip chart recorder. The station is equipped with electrical power and a telephone with a telemark. This instrumentation is housed in a standard WSC metal shelter located on a concrete pad on the left bank and on the upstream side of the highway bridge at Apohaqui. Streamflow discharge measurements during high and medium stages are taken from the bridge. Low water and ice cover discharge measurements are made by wading, or through the ice, in the vicinity of the gauge.

The stage-discharge relationship for this station has been stable for the high and medium stages. The low water portion of the relationship is not so stable and is characterized by a series of stage-discharge curves. The bed material is composed of a sandy-gravel texture. The stability of the measurement section is documented in Figure 2, where several cross-sections over the period of 1963 to 1984 are superimposed.

The Kennebecasis River at Apohaqui has natural flow records. Water quality data are also available at this station.

2.2 Basin Description and Hydrology

The study area (watershed) consists generally of the Upper Kennebecasis River and associated tributaries, above the highway bridge at Apohaqui, N.B., as shown in Figure 3. The total watershed area above Apohaqui is 1100 km^2 and the river flows in a southwesterly direction toward the Saint John River to the west. The Kennebecasis River has three major tributaries, having roughly equal watershed areas and accounting for more than half of the basin to the gauge at the Apohaqui bridge; Millstream River joins the Kennebecasis from the north, just upstream of the Apohaqui bridge, Trout Creek enters from the southeast within the Town of Sussex, some 8.5 km upstream from Apohaqui; and Smith Creek enters from the northeast, a further 1.9 km upstream. The watershed area of the Kennebecasis River above Smith Creek is 338 km^2. A schematic of the watershed area is given in Figure 4.

The Kennebecasis River and its main tributaries are characterized by relatively narrow rivers in shallow channels flowing through wide flat valleys.

The Kennebecasis River, with a channel width of 20-40 m, has an associated flood plain which is 400-1500 m wide. Smith Creek, with a channel width of 10-15 m, flows through a flood plain 250-1000 m wide, and Trout Creek has a channel width of 15-20 m and an associated flood plain 250-1000 m wide. Near the Town of Sussex, located at the confluence of the Kennebecasis and Trout Creek, the combined flood plain width is in the order of 2500 m.

Within the study reach, some of the river slopes range as follows:

Kennebecasis	0.0002 - 0.0012
Trout Creek	0.0012 - 0.0040
Smith Creek	0.0003 - 0.0013

The Kennebecasis River is characterized by flat channel slopes, extremely meandering channels, oxbows and cutoffs, and relatively fine grained channel materials.

Flooding of low lands in agricultural regions in the Kennebecasis River Basin is an annual occurrence. Flooding, sufficiently severe to be newsworthy, along the Upper Kennebecasis River has been recorded since 1854, and has occurred an average of about once every 5 to 6 years. Approximately 50 percent of floods are spring freshets, 40 percent mid-winter thaws and 10 percent fall floods. Roughly 75 percent of floods are related to rainfall and/or snow melt runoff and the remaining 25 percent to the formation of ice jams.

Floods are of relatively short duration with peaks generally of only a few hours duration. The terminology "flash floods" is applicable to many high water events in this basin. Flooding may be throughout the river basin or confined to one or more of the smaller tributaries, generally Trout Creek, Wards Creek or Parsons Brook.

The Kennebecasis River to the hydrometric gauge at Apohaqui (Station No. 01AP004) has a circular shaped basin approximately 40 km in diameter; the length (meander) of the river to Apohaqui is approximately 40 km.

There are no natural lakes of any consequence in this natural flow basin.

The main physical features and runoff characteristics of the Kennebecasis River at Apohaqui are presented in Table 1 (updated from Pol, 1982).

2.3 Land Use and River Sediments

One means to advance the understanding of the possible sources of river sediments recorded at the Apohaqui sampling station is to determine the land use practices employed and the associated land cover present in the watershed above Apohaqui. The Canadian Land Inventory (CLI), circa 1970, provides a descriptive overview of the landscape in the total Kennebecasis Basin. Although this description includes an additional area of the basin below Apohaqui (approximately 300 km^2), the statistics obtained are representative of the watershed above the sampling point at Apohaqui.

In the Kennebecasis River Basin, agricultural row crops often associated with higher rates of soil erosion, were not present in large enough areas to be recorded. Other more stabilizing land covers occured in the following percentages:

Forest	67.9
Pasture	23.9
Unimproved (grass)	4.6
Unimproved (shrub)	2.3
Wetland	0.7
Urban	0.6
TOTAL	100.0

A field reconnaissance was undertaken in the fall of 1986. This period provided a good temporal indication of the amount of fallow land (bare soil) that is exposed to the winter freeze and thaw cycle (especially when a blanket of snow is not present) and the spring runoff season. Bare soil on the sloping topography, as found in this watershed, is susceptible to the erosion of the soil and its subsequent runoff. As well, activities other than farming, such as surface extraction and urban construction, in many cases on relatively flat terrain, are also potential sources of river sediment.

The field survey supported the above CLI statistics. Very little of the basin's area was observed to be in fallow. On the fallow fields noted, there were many cases of plow-furrows running down slope on land adjacent to water courses (Plate 1). Also large forest cut-over areas were located above or below fallow fields. In combination, a forest cut-over and a fallow field on a slope act as a conduit for rapid sediment laiden runoff (Plate 2). The specific harvesting practices followed and when the forest was cut in this example are unknown. This forest cut-over is covered in a litter of slash.

In the many stream locations where a visual check was made of water clarity, only one occurrence of turbid/coloured water was observed. There are two major land users where the turbid water occured, one involved an agricultural operation and the other an extraction process. No determination was made of either the type or the source of the sediment/coloured water, noted on the South Branch of the Kennebecasis River at the highway bridge on the Trans-Canada Highway near Penobsquis.

As the oxbows on Plate 3 illustrate, much of the Kennebecasis is of low stream gradient. Bank erosion is present on the active river channel as seen in the same photograph. The angle of the spruce tree in Plate 4 is another indication of stream bank erosion. The protection offered the river bank by the natural low vegetated levee on the right bank of the Kennebecasis at the Apohaqui bridge (Plate 5) is in sharp contrast to the left bank (Plate 6). The river appeared to be visually sediment free at Apohaqui during this field survey; the river stage was low.

Land cover changes, when left to nature, in many cases tend to decrease the amount of soil erosion as well as the ability of runoff from precipitation to conduct eroded and other materials to stream channels. Some agricultural land, especially where located on slopes, is reverting to forest cover as are large cut-over areas that have been restocked with softwood species such as jack pine and spruce (Plate 7) as seen near Pleasant Ridge. Other forest cut-overs are now converted to commercial blueberries (solid mat cover), as is abandoned traditional farmlands seen south of Goshen.

Sediment movement results from the more limited activities such as using shallow stream beds, e.g., Smiths Creek (Plate 8), as crossing locations for farm machinery and cattle. This example also illustrates slope stabilization, i.e., the natural vegetation on the steeper slope of the older river terrace (see arrow) in the background of the photograph.

The future use of the land in this basin is expected to continue in farming ventures since 25.8% of the watershed falls within the relatively high CLI agricultural soil capability rating. Forestry appears to be encroaching on agricultural land, while at the same time, ensuring slope stability to some of the 20.2% of the basin's agricultural land that is limited by adverse topography, i.e., steep slopes. Forest harvesting, on the other hand, is a counter factor to the stablizing effect of forest restocking where runoff is considered.

The underground extraction of potash is another land use in which there are reported plans for expansion. Industrial and municipal waste disposal and landfill (Plate 9) sites were noted throughout the watershed adjacent to stream courses. The number of these potential point sources of sediment is expected to increase.

This basin varies considerably in the degree of slope. There is a limited number of large agricultural operations (dairy, hogs, sheep and poultry), extraction, construction and forestry activities that all could have a potential effect on the sediment loadings recorded at the Apohaqui gauging station. Bank erosion, although, is the major source of the recorded sediment loadings. There is a limited amount of fallow, in particular, as associated to crops of potatoes (Plate 10). There is a majority of fields in grass cover (Plate 11) and there is a natural restocking of abandoned farmland and replanting of forest cut-overs. These are some of the factors responsible for the improvement in the water quality of the basin, but little change is required to rapidly harm a river system. One environmental indicator that supports the conclusion that water quality is improving, is the increase in salmon stocks in the Kennebecasis Watershed in recent years (Personal Communication, B. Keating of DFO, Sussex, N.B., based on excerpts from Provincial Angling Reports).

3.0 SEDIMENT TRANSPORT DATA

3.1 Data Collected

The available data set for the Kennebecasis River at Apohaqui consists of the following:

1. suspended sediment concentrations of depth-integrated samples;
2. suspended sediment loads;
3. particle size analyses of suspended sediment of depth-integrated samples;
4. particle size analyses of bed material samples;
5. dissolved solids concentrations;
6. water temperatures.

In this report only the first two data sets outlined above are considered. It was not thought appropriate to interpret the other data or to draw any conclusions due to the limited amount of information available in the other sets.

3.2 Sampling Procedures and Equipment

Table 2 shows the number of days in each month when sample concentrations were collected, over the period 1966-84. These samples were collected using manual sampling and seasonal operation in 1966. From 1967 through 1984 data were collected using manual sampling and continuous operation throughout the whole year. The sampling effort was concentrated during the spring months when flows were high; however, the sampling frequency also increased in October and November. This is also a time of higher runoff. The higher frequency of sampling during high flow periods is illustrated by Figure 5, a flow duration curve and sediment sampling bar chart. This shows, for example, that 47% of the samples were collected during the higher flows that occurred over 30% of the time.

The sediment samples are taken by an observer from a single vertical, using a D49 sampler. The single sampling vertical is referenced as a chainage point of 29.9 metres from the left bank on the Apohaqui highway bridge.

Detailed sediment sampling over the cross-section was carried out in the late 60's and early 70's. This consisted of collecting depth-integrated samples at five or six locations across the river. These detailed surveys were used to obtain correction coefficients to be applied in calculating the mean sediment concentration for the cross-section from the single sampling vertical. The coefficients were not found to be significant (approximately equal to "1") and are not used in the calculations.

Bed material samples were taken from this site during the period 1967 through 1978. Water temperature information is also available.

3.3 Data Presentation

Calculated daily mean concentrations, suspended sediment loads, and grain size analyses of bed material and of suspended sediments are contained in the annual sediment data publications for Canada, issued since 1965, e.g., "Sediment Data, Atlantic Provinces, 1984", Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa, Canada, 1986 (Environment Canada, 1965 to 1984). The Kennebecasis River data set starts in the 1966 issue.

Table 3 presents a summary of the flow and suspended sediment data by year. Monthly and annual sediment loads are listed in Table 4 for the period of record to 1984.

3.4 Representativeness of Sediment Record Period

Frequency plots of annual flow volume and annual maximum daily discharge for the 1962 to 1984 hydrometric record are shown in Figures 6 and 7, respectively. The years in which sediment loads were not measured (1962 to 1966, inclusive) are indicated by a circle around the data. Based on these figures, it appears that the sediment program operated throughout the entire range of recorded discharges, although, this range may or may not be good in comparison to nearby sites with longer records.

Another method of illustrating the representativeness of the period of sediment record to the long-term conditions is shown in Figure 8. The sediment program began during a period in which both flow and suspended sediment load were near to mean conditions. From that point onward, the flow and suspended sediment data sets do not appear to show trend or of being anomalous in the statistical sense.

It should be noted that the above paragraphs are only for the 1962 to 1984 period. Although the range in flows is good, it by no means covers the entire range of flows possible at this site.

4.0 INTERPRETATION OF DATA

4.1 Suspended Sediment Loads

The annual flow volume in cubic decametres recorded at the Apohaqui station is shown on Figure 9. The period of record begins in 1962, however, for this report the mean has been calculated since 1967. This corresponds to the sediment data period of record. A mean value of 865,000 dam^3 is shown on this figure. By dividing by the drainage area in square kilometres the mean depth of runoff over the basin is found to be about 790 mm. Figure 9 also displays the suspended sediment load in tonnes passing by the Apohaqui station each year. The mean value of 35,800 tonnes is seen on this figure. Assuming, like the above data, that the production of suspended sediment is uniform over the basin a unit value of 32.5 tonnes/km^2 is calculated. However, sediment production is more likely to be from relatively few areas and most probably the river banks themselves. Therefore the unit value must be taken with this qualified assumption at all times. The annual data sets used to produce Figure 9 are tabulated in Tables 4 and 5. The sediment movement is seen to be much above the mean in 1979 and 1981. These same years are also seen to be relatively much greater flow volume years.

From Table 4, the range of annual suspended sediment data is seen to vary from a low of 19,500 tonnes in 1969 to a high of 69,200 tonnes in 1981. This range includes nearly a four fold variation. Comparing the range in flow volume over the same time period shows only a two fold variation. This leads to conclude that more than runoff influences the suspended sediment movement. The numerous physical characteristics, some static some dynamic, are influening the sediment movement at times more than the basin runoff. The suspended sediment movement within a year varies considerably. From Figure 10, it can be seen that most sediment moves during the October to May, inclusive, time period. The lines of flow and sediment on Figure 10 are the mean of all daily values in the years 1966 to 1984, inclusive.

The amount of flow or suspended sediment in any month can be expressed as a percentage of the annual value. Figure 11 shows the relative percentages for each month. April, the normal spring freshet month, has about 20% of the annual flow volume and about the same suspended sediment volume. It can also be seen that from December through to April the percent of sediment is greater than the corresponding percent of flow. The reverse situation occures from May to September each year. This pattern is broken by the October and November months.

Natural variation from year to year gives scatter to a time series, however, at times change may tend to go in one direction more often. Mass curves are useful to show if trends are occurring. Figure 12 is a plot of cumulative sediment and flow data. Some variation, as expected, is seen but overall the line is not showing a change in angle. It appears that during the sampling period that a near steady state condition exists. Further tests were done on the data sets using non-parametric tests to look for trend, homogeneity, etc. The annual total discharge data set was found to have a slight trend but not statistically significant. No trend was found in the suspended sediment data set.

A relationship exists between the sediment movement and basin runoff. The monthly suspended load and total discharge are plotted in Figure 13. Overall, a relationship exists using all of the data points, however, this may be a mix of distinctly different periods or seasons. A trend is seen towards greater loadings on the rise to peak period flows and also towards greater sediment load variability during the high flow periods. No monthly relationships were attempted in this report.

The prediction of total annual suspended sediment load can be done knowing the total annual discharge. The variabilities within the year will be smoothed out to some degree. Figure 14 displays this relationship. A standard error of estimate of $\pm$26.8% for the function "Load = $2.35 \times 10^{-4}(\text{Flow})^{1.38}$" demonstrates a reasonable relationship. There is a relationship between flow and suspended sediment, however, unqualified use of such curves may be misleading. The data sets and statistics behind the curves must be considered. One inspection of the data behind the curve is to determine how fast sediment is being produced. The annual loading value is not from a smooth production throughout each year. A large fast runoff could produce most of the years sediment but this is not seen in the annual value. Figure 15 shows how much sediment was produced in 10% and 1% of the year. The maximum loads occurring in 3.7 and 36.5 days are shown. On average, the maximum 3.7 day load carries 20% of the annual load while the maximum 36.5 day load carries about 40% of the annual value.

Time averaging should dampen the range of data therefore any relationships on a time scale less than one year are expected to be less accurate. To investigate this a relationship was developed between the flow at the time the sediment sample was taken. These are referred to as instantaneous data. The samples taken in 1984 were used to develop two functions. A standard error of $\pm$104% was found for the relationship using all the data for the entire year while the standard error reduced to $\pm$83% by just using the March/ April/ May data of 1984. These results are found in Table 6. In a previous report (Northwest Hydraulic Consultants, Ltd., 1986) it was found that sediment rating curves constructed from daily data have correlation coefficients that vary from 0.6 to 0.9 and the slopes of the fitted lines varied widely from year to year. No daily ratings were attempted in this report.

As each year of successive data are gathered more of the variability is seen in the long-term data set. In theory, with long-term climatic changes being the only difference a steady state condition will be approached. When the standard error has been reduced down to the natural or sampling error enough data should have been collected. Figures 16 and 17 display this relationship. After 18 years of record the standard error of the mean is reduced to about 10% for both concentration and load. The percentage gain by getting another year of record is less than 1%. Further data collection at this site will not substantally improve the standard errors of estimate for mean annual concentration and mean annual load. The outliers found in Figure 16 are associated with the flood of February 12, 1981.

5.0 PROGRAM EVALUATION AND RECOMMENDATIONS

The suspended sediment data collection program at the Apohaqui hydrometric gauging station represents sediment loadings and yield from an agricultural environment. Although there is a limited amount of fallow land in the basin, the majority of which is in the Sussex area, it is believed that most of the river sediments are produced by the agricultural activities and by stream bank erosion. In addition, it is concluded that the dominant sediment related events occur with the spring peak flows.

The findings of this interpretation indicate that the data collected to date are sufficient to define the present-day suspended sediment regime of the Kennebecasis River. In particular, the analyses indicate the following:

(1) the range in the data is good, i.e., it covers the range of recorded flows, for the period 1962 to 1984
(2) estimates of the mean characteristics of the suspended sediment regime can be improved only slightly, if basin use does not change
(3) annual variability is well documented, for the period 1962 to 1984
(4) any presence of trend in the data set is not noticeable, for the period 1962 to 1984.

It should be noted that our knowledge of how representative these data are of long-term conditions is inadequate. However, for many engineering needs sufficient data now exist, i.e., total annual loading can be approximated within $\pm$30% using the discharge as the estimator. To estimate sediment concentrations or loadings on a monthly or daily basis, using only the discharge as the independant variable, however, would produce results with errors in the hundreds of percent.

A general conclusion is that the sediment sampling program for this station over the last 18 years, has resulted in a data set covering most of the recorded flow range. Aside from a few too many samples in times when no sediments or extremely small amounts were moving, the sampling program is well done.

In a recent assessment of sediment issues in the Atlantic Provinces (Washburn & Gillis Associates Ltd., 1985), it was recommended that a basic network of long-term stations be retained. This followed from the need to know background or natural levels throughout the Atlantic Region; natural levels of sediment yield from this basin (disregarding bank erosion), as sampled at Apohaqui, are believed to be low. This sediment station does not meet the criterium, as recommended by the consulting report, of monitoring natural sediment yield of a major sediment zone. This is mainly due to the agricultural activities in the basin.

As the Apohaqui sediment station is the only station within the sediment zone as outlined by T. Ingledow & Associates Limited in 1970, this station should be discontinued with the operation and maintenance money relocated to another suitable site within the same zone. Other locations within this zone were outlined in the report entitled, "Sediment Survey Network, New Brunswick, A Five Year Plan". Therefore the author recommends the following:

(1) To discontinue the sediment sampling program at Apohaqui on the Kennebecasis River and relocate at another hydrometric site within the same sediment zone. A second natural but independent sediment data set of at least 10 years in the same zone will further clarify the zone delineation and allow for data transfer testing within the zone.

The station at Apohaqui should be discontinued in the same fiscal year as the new location is brought on line. This will ensure that there is continuous record within the zone and show immediate re-allocation of the O&M funds. The capital funds, if any are needed, should be identified in the 1987/88 fiscal year with the station being discontinued in 1988/89 fiscal and coincident with the start up of the new station in the zone.

(2) The sampling strategy at the new site should be revised. Approximately 90% of the sediment load is transported during the eight month period of October to May; whereas, in the low load months of June through September, 35% of the sediment samples are collected. The strategy should be to reduce the number of samples taken during the dry weather period.

(3) Research involving multiple regression techniques relating sediment loadings versus watershed physiographic and hydrologic parameters is needed. The relationships developed only between flow and sediment are not considered to be sound. It would be better to relate sediment movement to physical and climatic parameters in addition to the flow parameter. The existing data set from the Kennebecasis River would provide a good basis for this research.

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8. T. Ingledow & Associates Limited, "Hydrometric Network Plan for the Provinces of Newfoundland, New Brunswick, Nova Scotia and Prince Edward Island", prepared for the Government of Canada, Department of Energy, Mines and Resources, December, 1970.

9. Pol, R.A., and Elhadi, N.D., "Sediment Survey Network, New Brunswick - A Five Year Plan", report no. IWD-AR-83-WRB-39, prepared jointly by IWD, WRB, Environment Canada and WRB of the Department of the Environment, New Brunswick, November, 1982.

APPENDIX A
(Tables)

TABLE 1

Runoff Characteristics of the Kennebecasis River at Apohaqui
Period 1961 to 1984

Drainage Area (km^2)	1100
Length (Meander) (km)	40
Area of Lakes (percentage of D.A.)	0
Recorded Minimum Daily Discharge (m^3/s) (on September 14, 1966)	1.01
Recorded Maximum Daily Discharge (m^3/s) (on February 12, 1981)	520 B
Recorded Maximum instantaneous Discharge (m^3/s) (on February 12, 1981)	639
Mean Annual Runoff (m^3/s)	26.0
Mean Annual Runoff (mm)	746
Years of Record	24

B-Ice Conditions

TABLE 2

Summary of Suspended Sediment Sampling Strategies

Showing Number of Days Sampled Each Month

Year	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Total
1966							4	6	4	4	12	7	37
67	1	3	3	17	28	13	15	11	14	12	10	9	136
68	4	5	13	18	9	13	10	8	10	16	20	11	137
69	4	5	14	24	16	9	13	15	17	11	19	16	163
70	3	7	10	23	20	13	12	16	13	17	15	2	151
71	3	3	14	24	13	9	16	17	13	17	17	7	153
72	5	4	13	12	21	15	12	11	11	19	19	10	152
73	5	5	17	14	15	9	17	14	10	9	17	21	153
74	2	6	14	14	12	9	18	9	17	15	6	12	134
1975	0	3	5	17	13	9	11	9	10	10	18	12	117
76	4	5	13	15	14	7	16	12	10	16	13	1	126
77	2	3	8	17	14	19	11	18	18	22	13	11	156
78	7	1	2	16	10	12	11	10	11	18	9	2	109
79	14	5	25	30	19	12	11	17	14	20	19	15	201
80	10	5	17	30	17	22	21	21	17	20	19	16	215
81	6	13	14	21	15	17	19	17	19	25	23	21	210
82	6	6	12	27	18	14	18	16	17	13	23	22	192
83	12	4	20	20	25	17	14	15	18	20	22	18	205
1984	8	17	18	27	16	18	19	14	13	11	10	10	181
Total	96	100	232	366	295	237	268	256	256	295	304	223	2928
% of Grand Total	3	3	8	13	10	8	9	9	9	10	10	8	100

Table 3

Summary of the Flow and Suspended Sediment Data Analyses

at the Kennebecasis River at Apohaqui Hydrometric Gauging Station

Annual Statistics

Year	Number of days Sampled	Mean Discharge (m^3/s)	Mean Concentration (mg/l)	Total Load (tonnes)	Basin Yield (tonnes/km^2)
1966	37	--	--	--	--
1967	136	30.6	32	31 000	28.2
1968	137	21.4	38	25 900	23.6
1969	163	21.7	28	19 500	17.7
1970	151	20.8	64	41 900	38.1
1971	153	24.0	37	28 300	25.7
1972	152	29.7	47	43 900	39.9
1973	153	27.0	40	34 400	31.3
1974	134	23.5	63	46 300	42.1
1975	117	23.9	33	25 000	22.7
1976	126	31.4	35	34 800	31.7
1977	156	33.1	44	45 700	41.6
1978	109	23.9	31	23 600	21.4
1979	201	40.2	49	62 400	56.7
1980	215	24.2	26	19 600	17.8
1981	210	40.2	55	69 200	62.9
1982	192	24.6	31	23 700	21.5
1983	205	25.4	31	24 700	22.5
1984	181	28.3	49	43 700	39.7
Mean :		27.4	41	35 800	32.5
Standard Dev. :		5.8	12	14 200	12.9

TABLE 4

MONTHLY AND ANNUAL SUSPENDED SEDIMENT LOADS AT APOHAQUI

YEAR	MONTHLY SUSPENDED SEDIMENT LOAD, TONNES PER DAY												ANNUAL LOAD (TONNES)
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1966	----	----	----	----	----	----	2.01	0.51	0.67	4.97	13.3	26.4	-----
1967	19.0	2.06	1.40	105	296	76.7	47.1	3.43	42.0	53.5	108	258	31000
1968	78.9	237	233	111	10.7	13.7	8.40	2.96	1.11	26.0	79.2	56.1	25900
1969	132	30.3	38.2	163	29.4	4.13	14.7	8.75	16.8	8.58	38.9	154	19500
1970	79.1	719	138	114	70.9	15.9	60.4	25.8	11.5	82.9	70.5	41.3	41900
1971	40.1	206	80.0	361	129	13.6	6.68	6.47	2.77	12.8	73.2	16.1	28300
1972	29.4	75.5	29.1	213	602	47.5	23.9	4.68	4.10	158	155	92.3	43900
1973	62.6	20.7	238	173	68.4	16.9	192	61.9	2.88	2.19	17.3	262	34400
1974	20.6	19.4	178	282	66.2	3.04	67.2	4.26	136	49.2	26.7	656	46300
1975	14.6	9.50	45.2	244	140	36.3	21.5	3.64	16.5	16.7	160	113	25000
1976	321	195	134	124	76.9	13.1	95.3	11.1	4.65	40.9	39.0	85.8	34800
1977	18.3	4.55	206	268	85.7	113	7.39	9.75	36.3	368	147	230	45700
1978	177	12.5	51.7	388	76.2	23.1	6.89	1.67	2.46	23.6	7.00	5.12	23600
1979	485	32.9	684	351	153	37.5	18.1	53.2	43.0	60.6	83.3	29.8	62400
1980	45.3	1.64	107	169	35.3	15.7	18.5	23.6	19.0	53.9	70.9	80.4	19600
1981	52.3	690	34.0	255	20.0	72.7	8.75	165	113	604	147	157	69200
1982	22.1	34.6	131	323	18.8	13.3	16.6	22.1	16.6	10.4	103	69.9	23700
1983	21.2	24.9	227	132	90.8	27.5	11.5	11.8	4.53	8.82	79.9	168	24700
1984	49.5	138	300	545	48.4	129	186	7.39	6.92	2.38	2.31	25.4	43700
MEAN	92.7	136	159	240	112	37.4	42.8	22.5	25.3	83.5	74.8	133	35800
% OF ANNUAL	8.0	11.1	14.2	20.7	9.7	3.1	3.7	2.0	2.1	7.2	6.3	11.9	100

TABLE 5

SUMMARY OF MONTHLY AND ANNUAL FLOWS AT APOHAQUI

KENNEBECASIS RIVER AT APOHAQUI - STATION NO 01AP004

MONTHLY AND ANNUAL MEAN DISCHARGES IN CUBIC METRES PER SECOND FOR THE PERIOD OF RECORD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	TOTAL DISCHARGE (dam^3)	YEAR
1961	...	...	...	...	...	28.2	6.88	2.43	3.47	16.4	33.4	22.2	...	...	1961
1962	30.0	9.43	11.8	66.8	16.7	8.76	23.3	13.8	26.8	27.6	49.4	20.2	26.6	838 000	1962
1963	17.4	14.7	11.8	62.6	60.3	9.43	5.22	7.16	9.13	24.7	55.8	26.6	27.1	855 000	1963
1964	13.0	10.3	23.2	61.7	34.0	7.36	5.84	3.77	8.07	8.24	14.8	56.7	21.3	673 000	1964
1965	23.5	10.6	26.8	36.8	28.1	7.87	3.36	2.48	1.82	3.10	8.85	12.0	14.4	454 000	1965
1966	8.26	6.19	42.8	36.0	24.7	8.43	5.10	2.67	2.95	7.31	10.4	16.6	14.8	466 000	1966
1967	16.6	5.61	8.45	42.8	101	26.0	18.5	7.61	15.7	35.7	31.7	61.4	30.8	967 000	1967
1968	16.2	20.2	46.8	61.4	15.0	12.4	6.13	3.26	2.16	7.86	29.3	36.6	21.4	675 000	1968
1969	13.8	9.86	16.8	70.0	33.0	8.64	7.13	7.46	8.70	10.7	27.7	46.6	21.7	685 000	1969
1970	8.54	41.6	13.6	29.2	24.4	16.9	16.3	11.6	10.4	28.8	28.0	13.2	20.6	656 000	1970
1971	16.1	41.0	27.8	103	83.3	12.3	8.00	5.86	4.43	8.19	12.4	8.78	24.8	787 000	1971
1972	17.2	13.8	17.2	66.8	102	36.6	10.8	7.61	4.88	25.7	66.8	24.1	28.7	838 000	1972
1973	21.1	21.6	46.4	42.1	24.1	15.2	38.6	26.1	8.89	4.27	13.1	61.1	27.0	851 000	1973
1974	14.6	12.4	26.6	42.6	27.4	14.4	17.6	4.71	10.1	22.2	16.2	60.1	23.5	738 000	1974
1975	13.7	8.80	24.8	65.8	64.6	14.8	7.80	3.46	6.33	8.10	35.2	24.2	23.9	762 000	1975
1976	47.1	65.2	34.4	54.6	41.6	13.1	26.0	12.8	8.46	24.0	24.6	35.7	31.4	994 000	1976
1977	16.3	8.50	43.6	66.6	46.3	48.0	8.50	6.48	11.6	66.1	23.0	37.2	33.1	1 040 000	1977
1978	83.7	18.2	20.6	60.3	38.6	11.4	4.96	2.39	2.23	8.16	8.33	8.83	23.8	753 000	1978
1979	77.6	20.1	76.7	56.3	62.6	26.3	8.86	21.2	19.7	38.7	46.6	22.3	40.2	1 270 000	1979
1980	28.4	8.66	36.4	61.7	27.7	12.2	12.3	12.3	9.62	22.2	32.1	36.1	24.2	764 000	1980
1981	18.7	114	31.6	77.1	23.6	31.1	11.8	16.6	7.22	46.0	61.3	67.7	40.2	1 270 000	1981
1982	16.2	20.2	24.1	67.0	27.1	10.6	8.86	10.7	10.6	8.61	20.6	27.2	24.6	776 000	1982
1983	16.1	16.1	66.6	61.6	26.6	23.6	8.20	9.31	4.90	8.10	21.7	45.8	25.4	800 000	1983
1984	13.7	46.6	60.2	63.4	38.2	34.3	24.1	8.83	6.43	4.63	8.13	14.8	26.2	694 000	1984
MEAN	33.3	23.2	31.6	63.0	43.2	16.1	12.7	8.86	8.60	16.6	27.7	32.8	26.0	820 000	MEAN

LOCATION - LAT 45 42 07 N DRAINAGE AREA, 1 100 km^2
LONG 65 36 05 W NATURAL FLOW

TABLE 6

REGRESSION ANALYSIS
INSTANTANEOUS DISCHARGE VERSUS INSTANTANEOUS CONCENTRATION
ONLY SAMPLED CONCENTRATIONS - USING 1984 DATA AT APOHAQUI

PERIOD JANUARY TO DECEMBER ALL DATA

Relationship: $C = 1.33\ Q^{0.765}$

Where: C = Instantaneous concentration in mg/l
Q = Instantaneous discharge in m^3/s

Statistics: $r^2 = 0.404$
$S_e = \pm 104\ \%$

PERIOD MARCH-APRIL-MAY ALL DATA

Relationship: $C = 6.39 \times 10^{-2}\ Q^{1.46}$

Where: C = Instantaneous concentration in mg/l
Q = Instantaneous discharge in m^3/s

Statistics: $r^2 = 0.589$
$S_e = \pm 83.1\ \%$

APPENDIX B
(Figures)

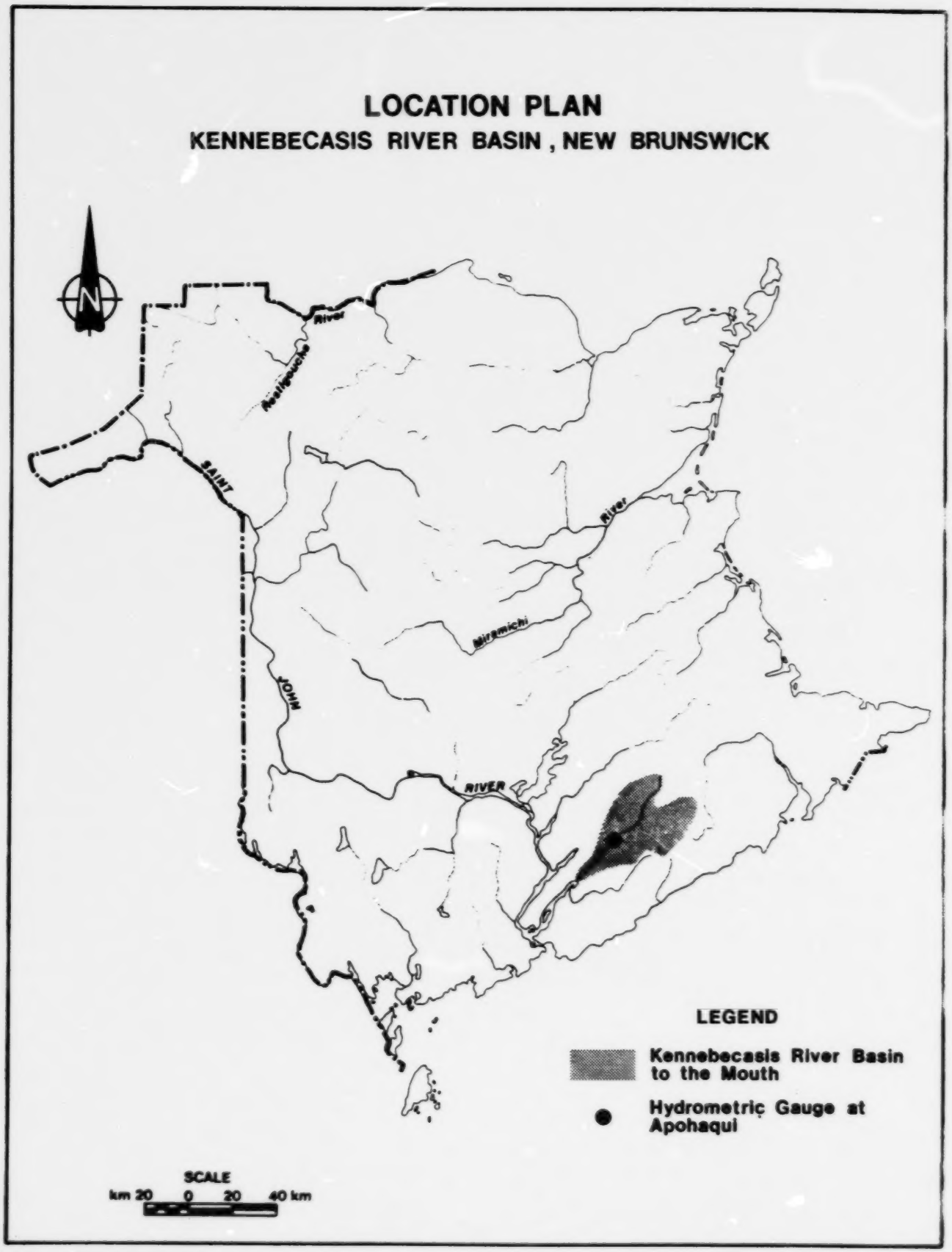

LOCATION PLAN
KENNEBECASIS RIVER BASIN , NEW BRUNSWICK
N
River
Restigouche
SAINT
JOHN
RIVER
River
Miramichi
LEGEND
Kennebecasis River Basin to the Mouth
Hydrometric Gauge at Apohaqui
SCALE
km 20 0 20 40 km

Figure 1

KENNEBECASIS RIVER CROSS-SECTIONS AT APOHAQUI BRIDGE

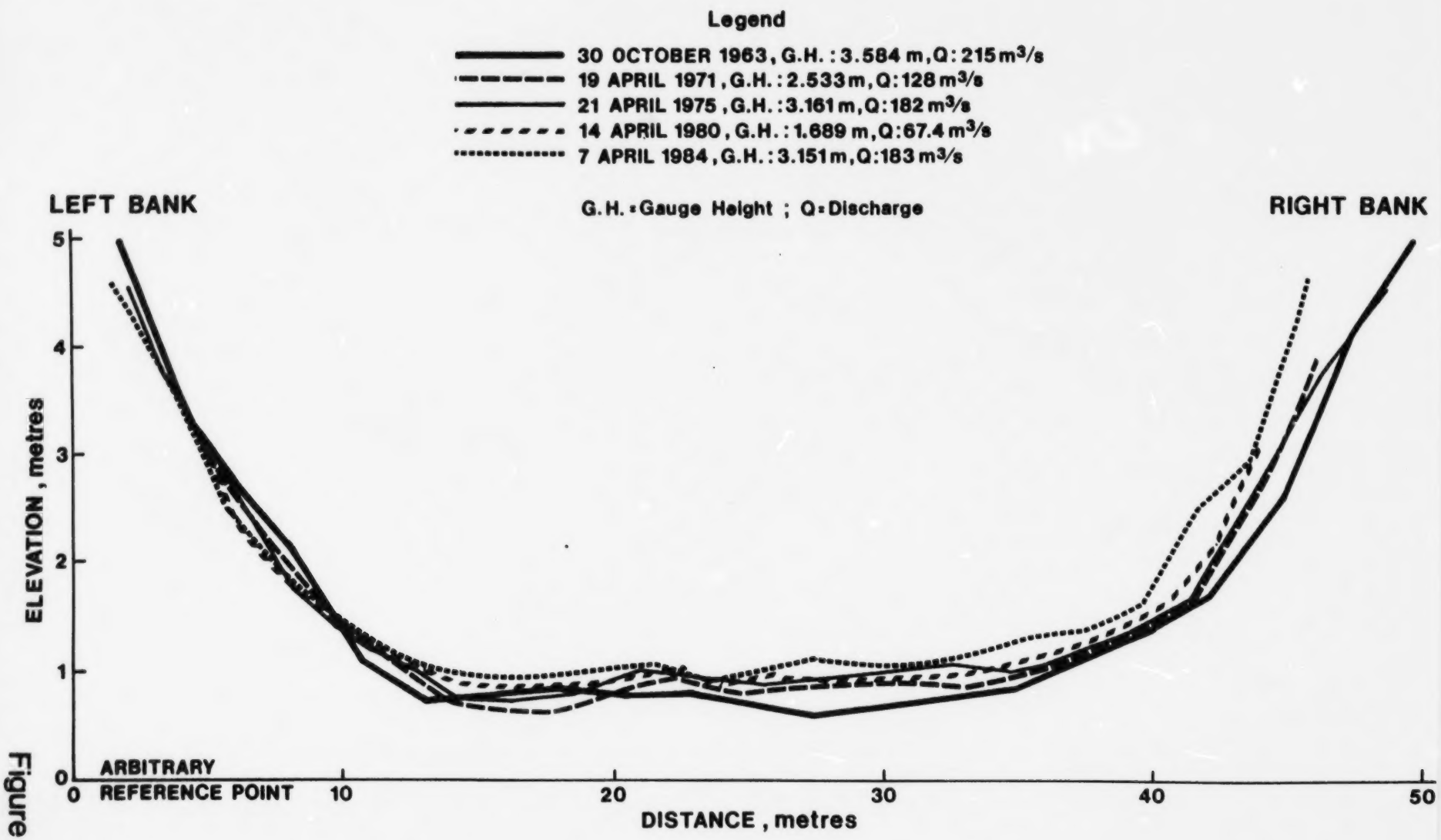


Figure 2

Figure 3 Kennebecasis Watershed above Apohaqui

Source : Reference 3

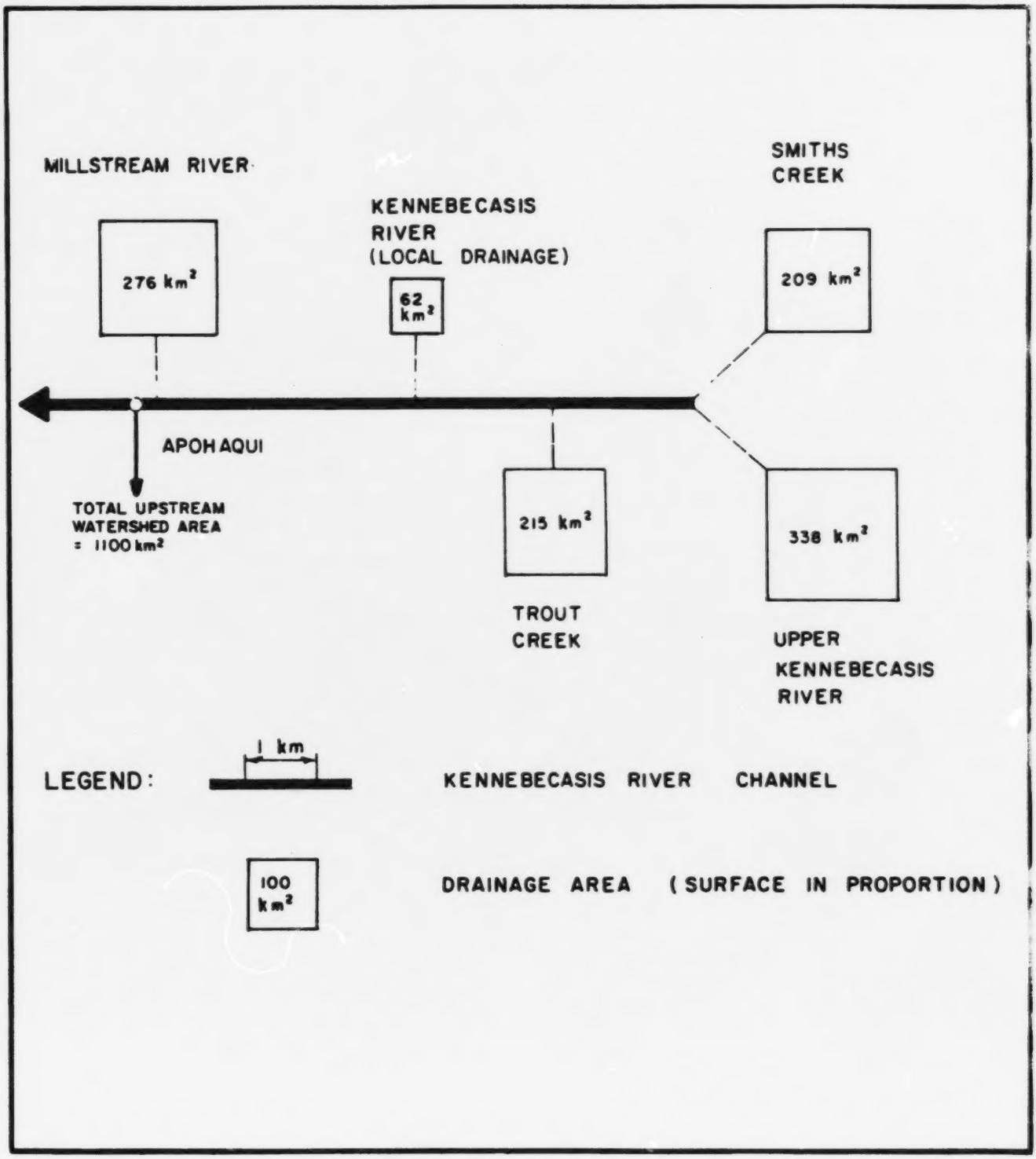


Figure 4 Schematic of Kennebecasis River Watershed Area Above Apohaqui

Source : Reference 3

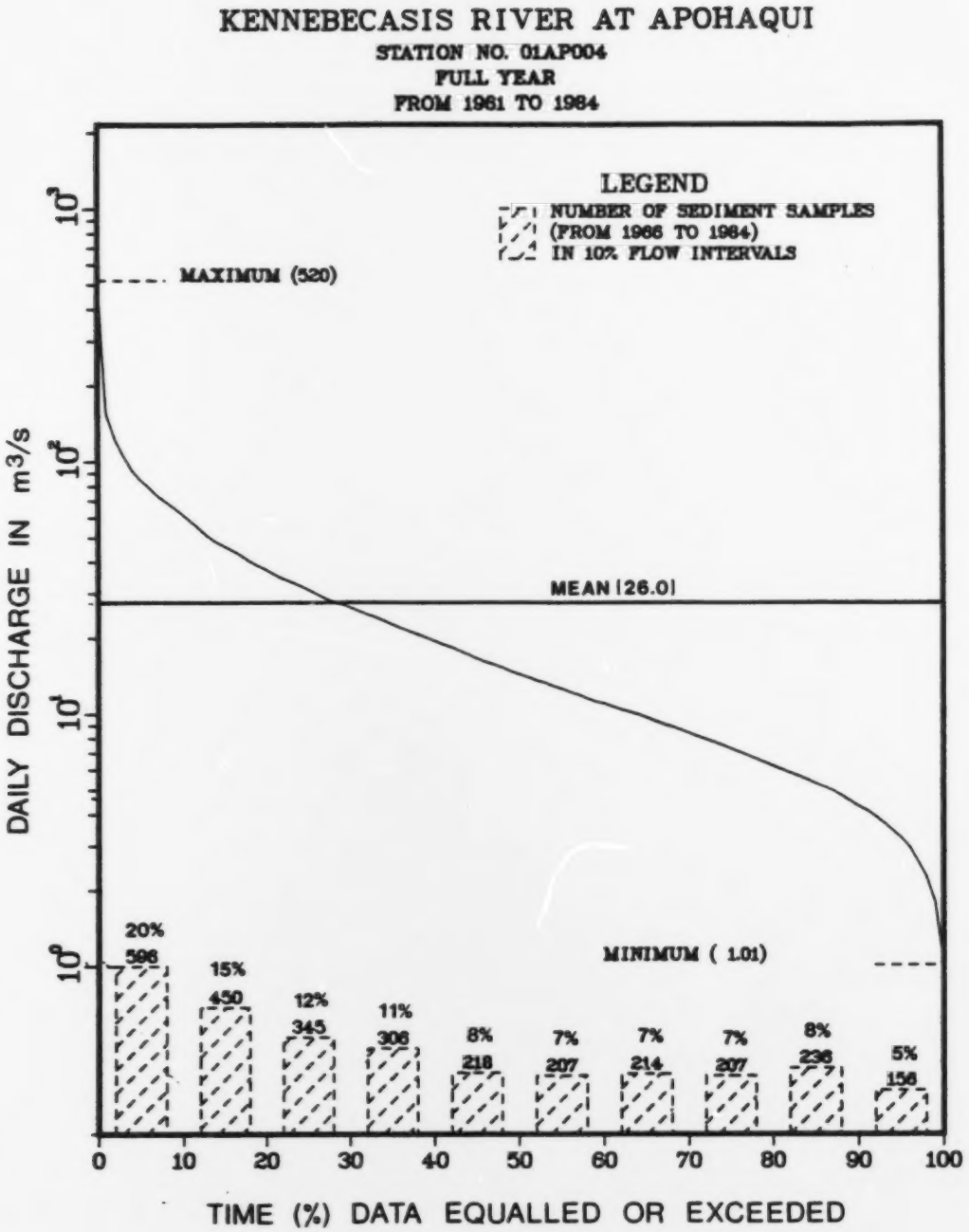


Figure 5 Flow Duration Curve and Sediment Sampling Bar Chart

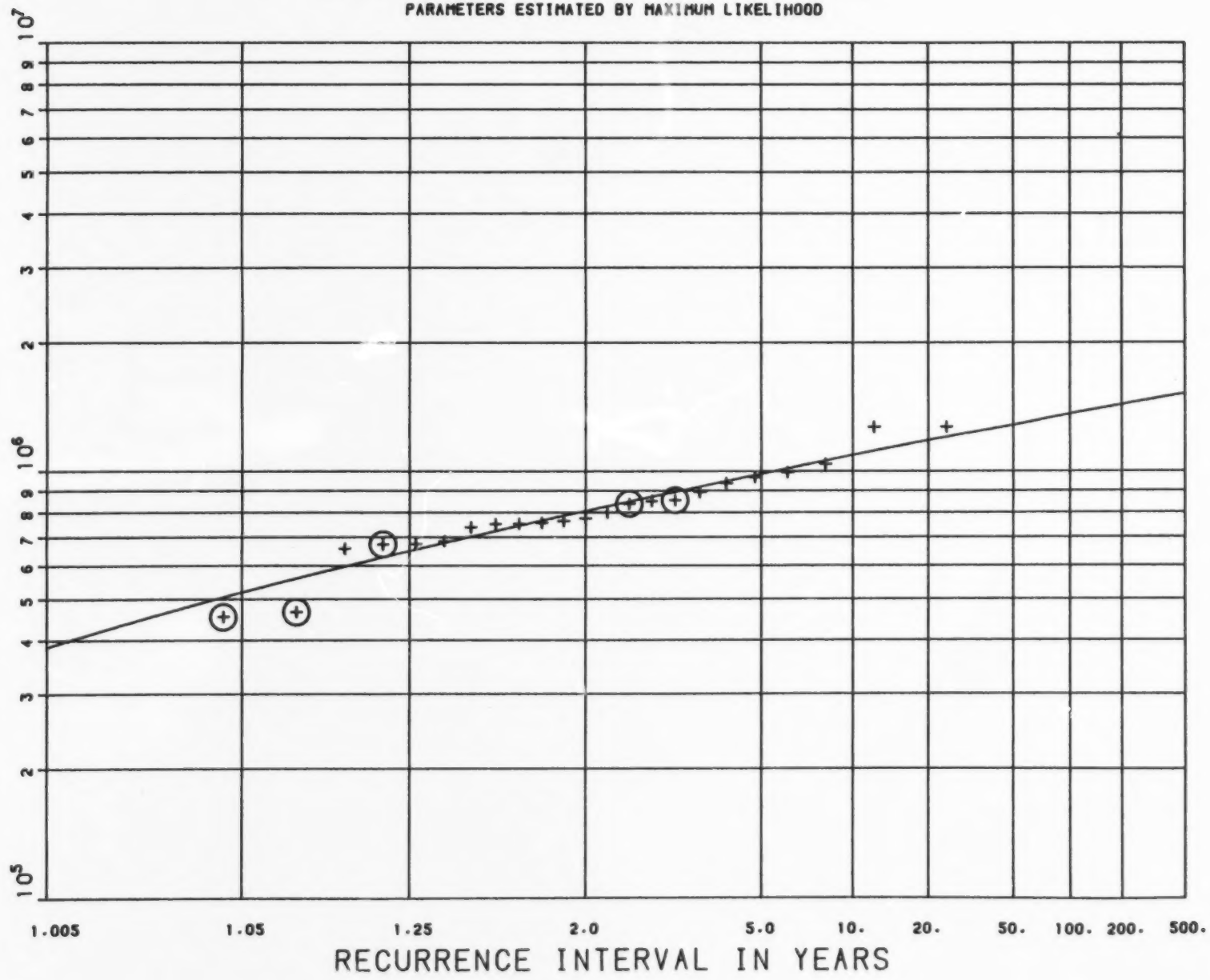


Figure 6 Frequency Plot of Annual Flow Volume

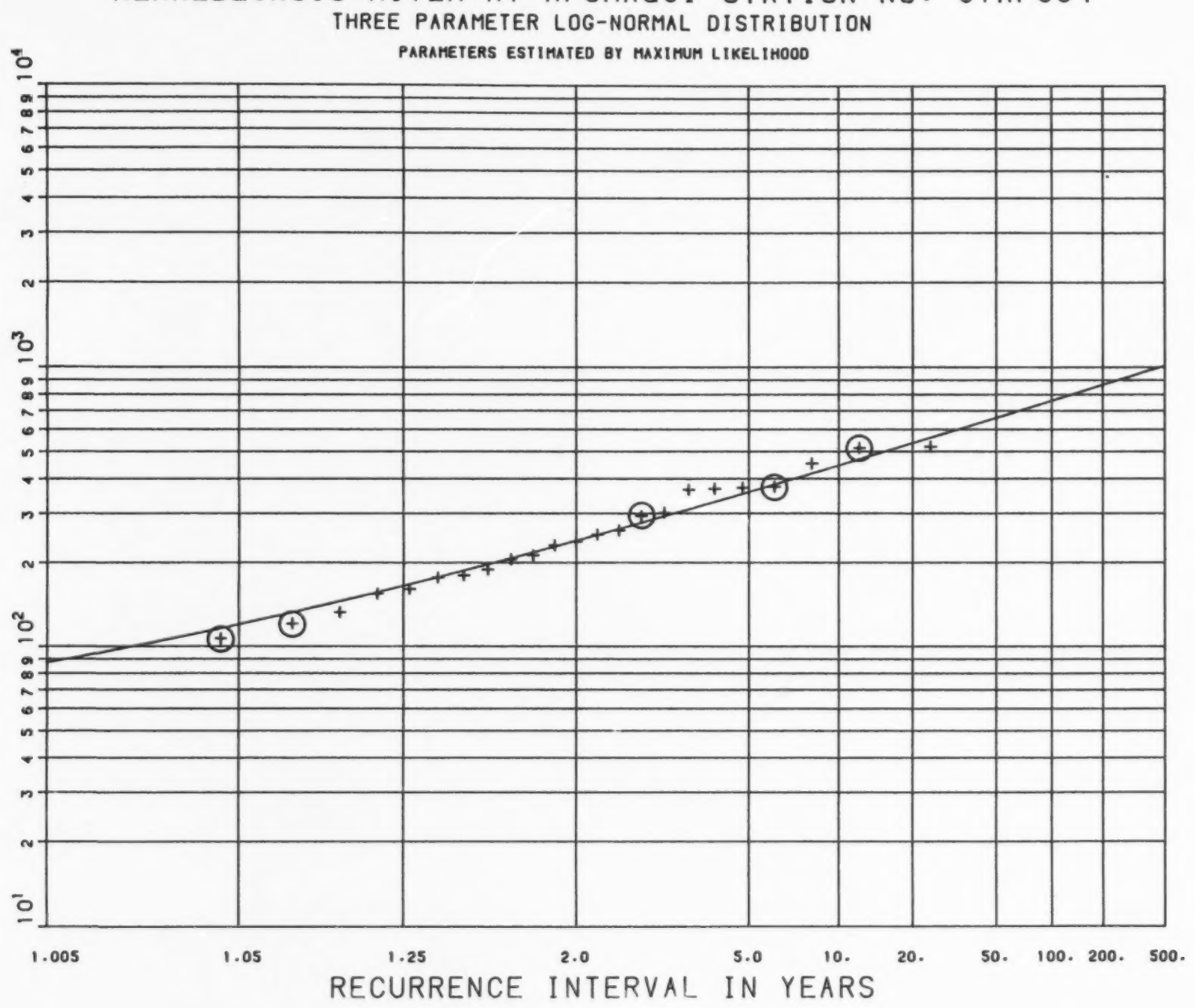


Figure 7 Frequency Plot of Annual Maximum Daily Discharge

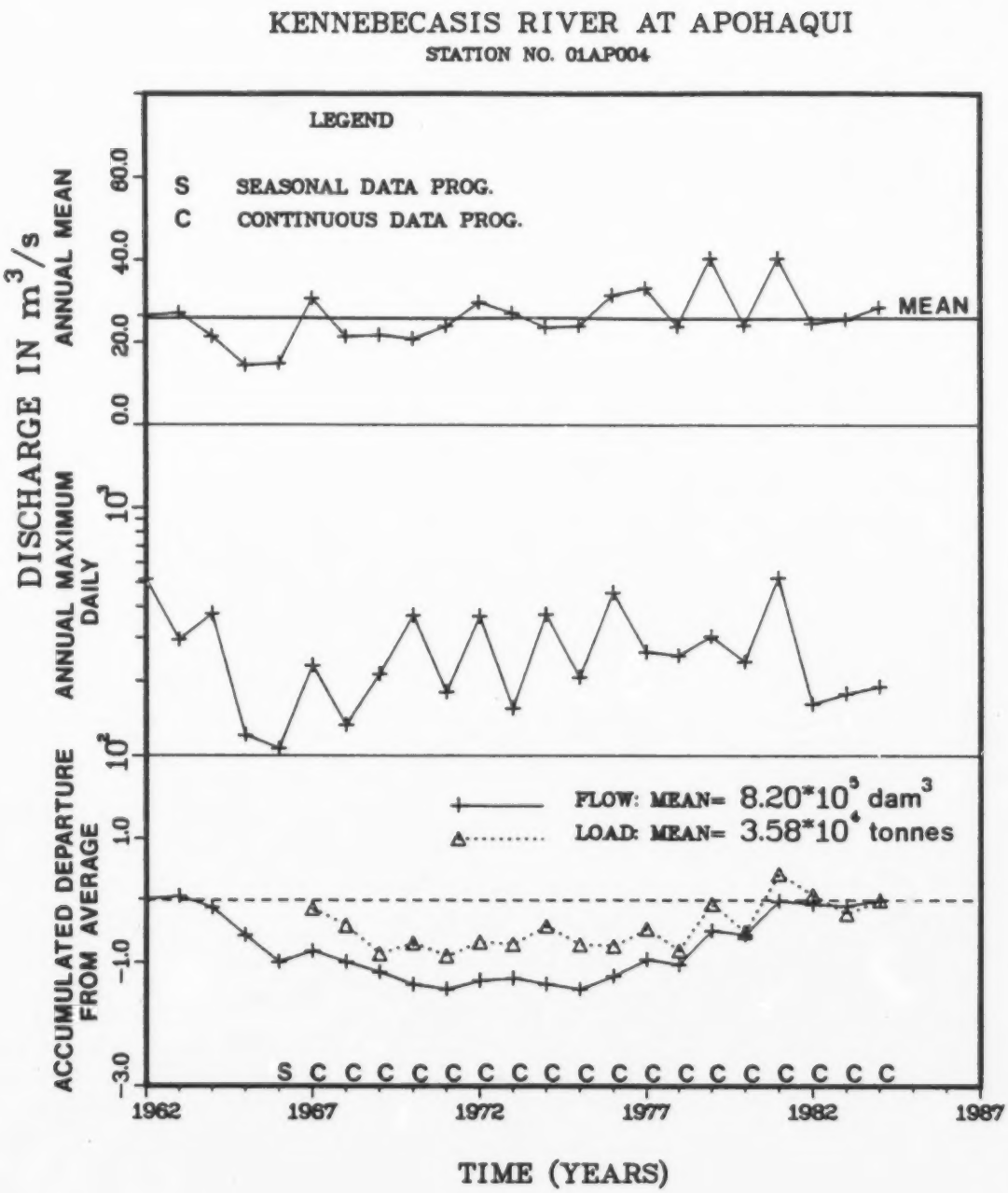
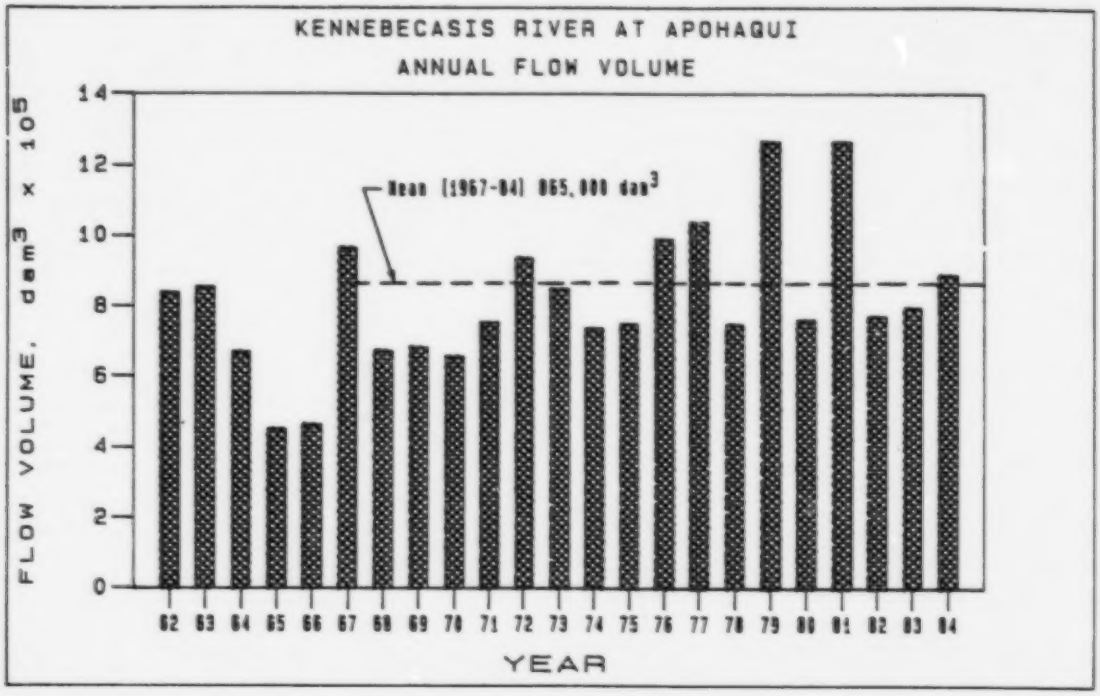


Figure 8 Flow History During Sediment Sampling Program


KENNEBECASIS RIVER AT APOHAQUI
ANNUAL FLOW VOLUME
FLOW VOLUME, dam3 x 10^5
Mean (1967-84) 865,000 dam3
0
2
4
6
8
10
12
14
82 83 84 85 86 87 88 89 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84
YEAR

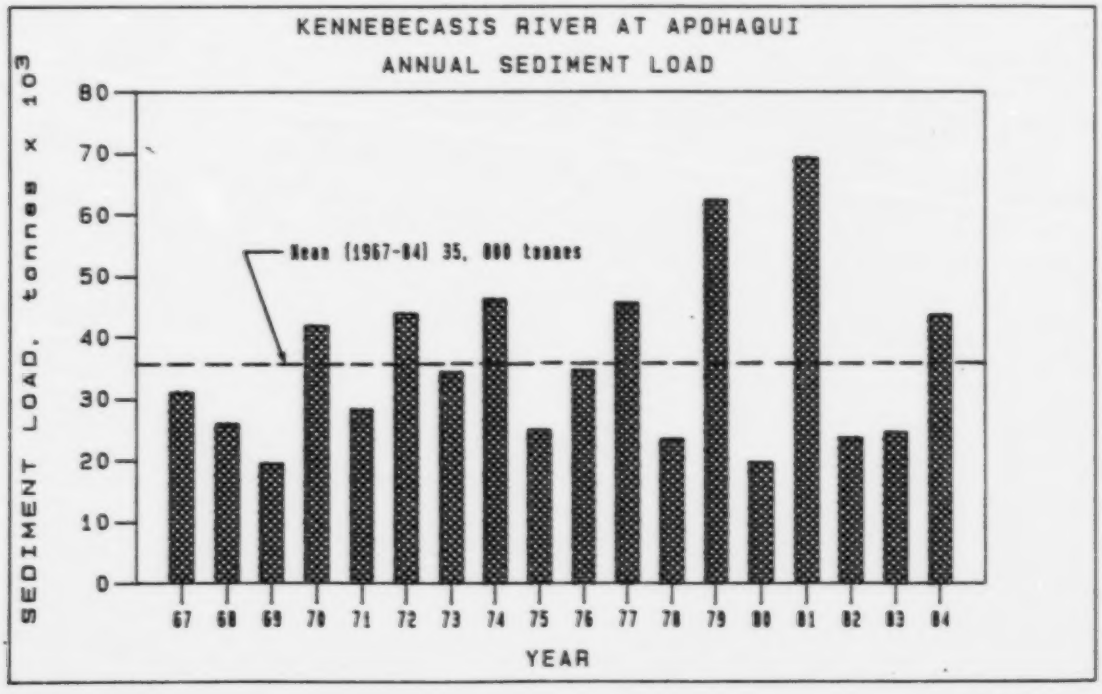

KENNEBECASIS RIVER AT APOHAQUI
ANNUAL SEDIMENT LOAD
SEDIMENT LOAD, tonnes x 10^3
Mean (1967-84) 35, 000 tonnes
0
10
20
30
40
50
60
70
80
67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84
YEAR

FIGURE 9

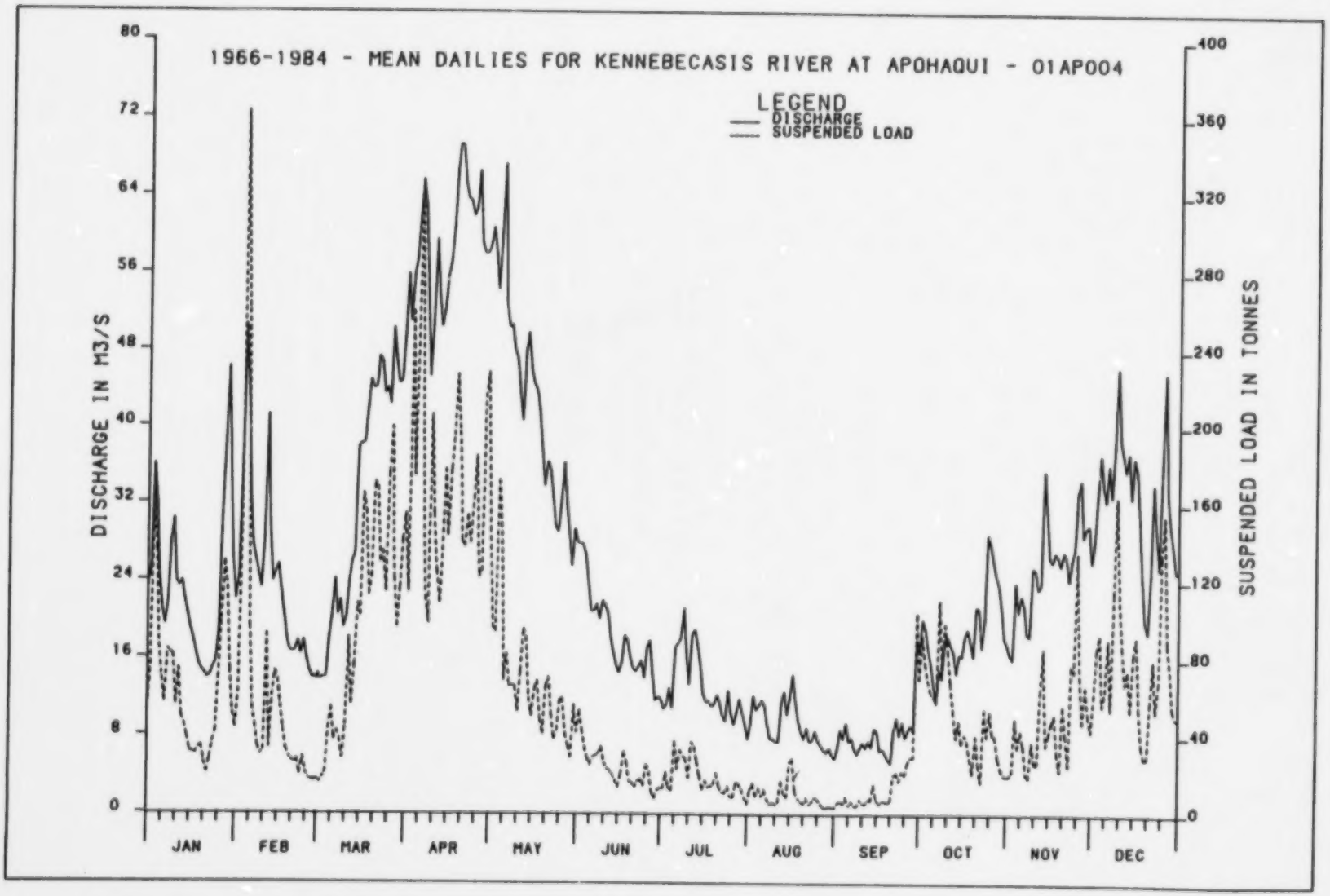

1966-1984 - MEAN DAILIES FOR KENNEBECASIS RIVER AT APOHAQUI - 01AP004
LEGEND
DISCHARGE
SUSPENDED LOAD
DISCHARGE IN M3/S
SUSPENDED LOAD IN TONNES
0
8
16
24
32
40
48
56
64
72
80
0
40
80
120
160
200
240
280
320
360
400
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 10

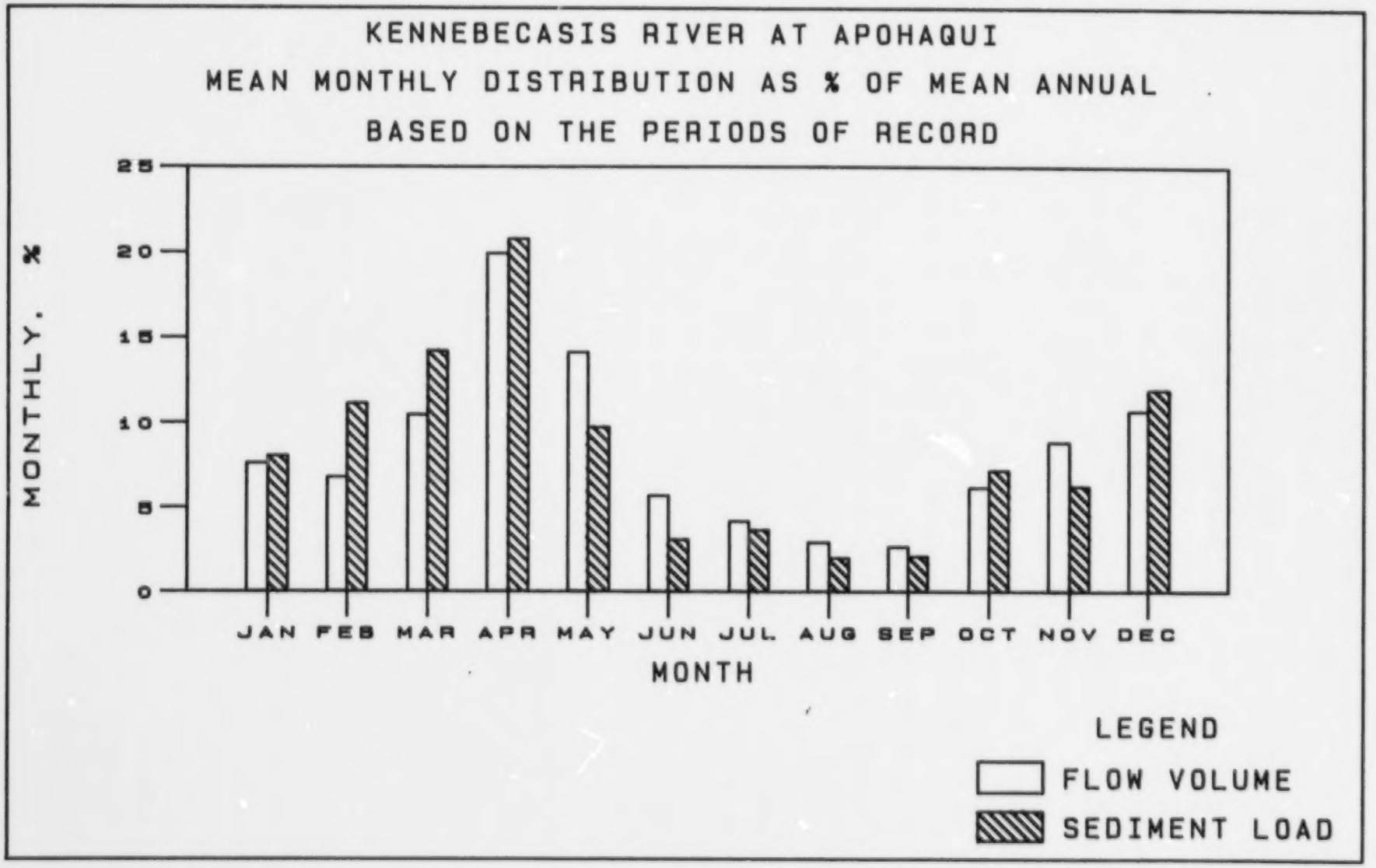

KENNEBECASIS RIVER AT APOHAQUI
MEAN MONTHLY DISTRIBUTION AS % OF MEAN ANNUAL
BASED ON THE PERIODS OF RECORD
MONTHLY, %
25
20
15
10
5
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH
LEGEND
FLOW VOLUME
SEDIMENT LOAD

FIGURE 11

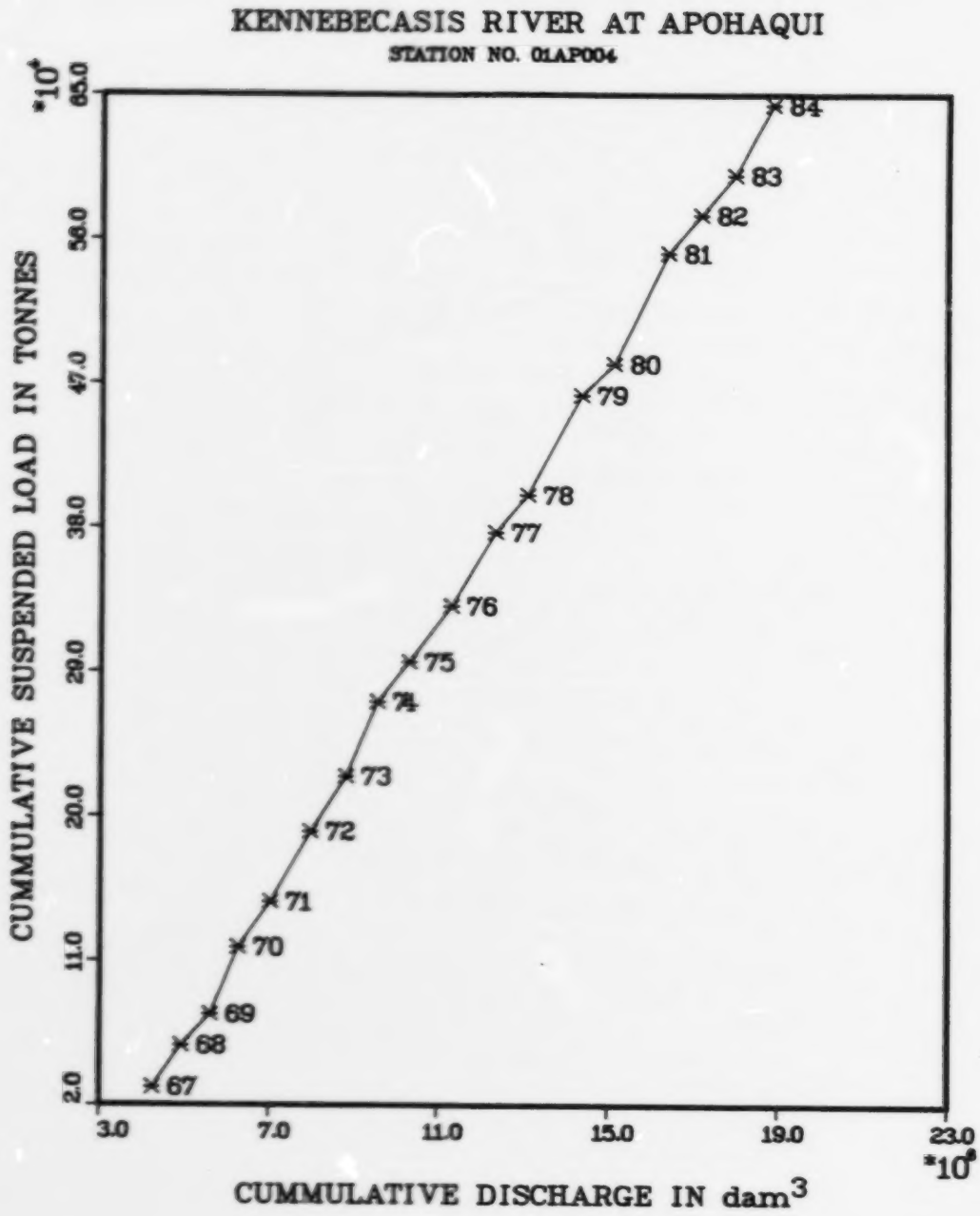


FIGURE 12 CUMULATIVE SUSPENDED SEDIMENT LOAD VERSUS CUMULATIVE FLOW VOLUME 1967 TO 1984

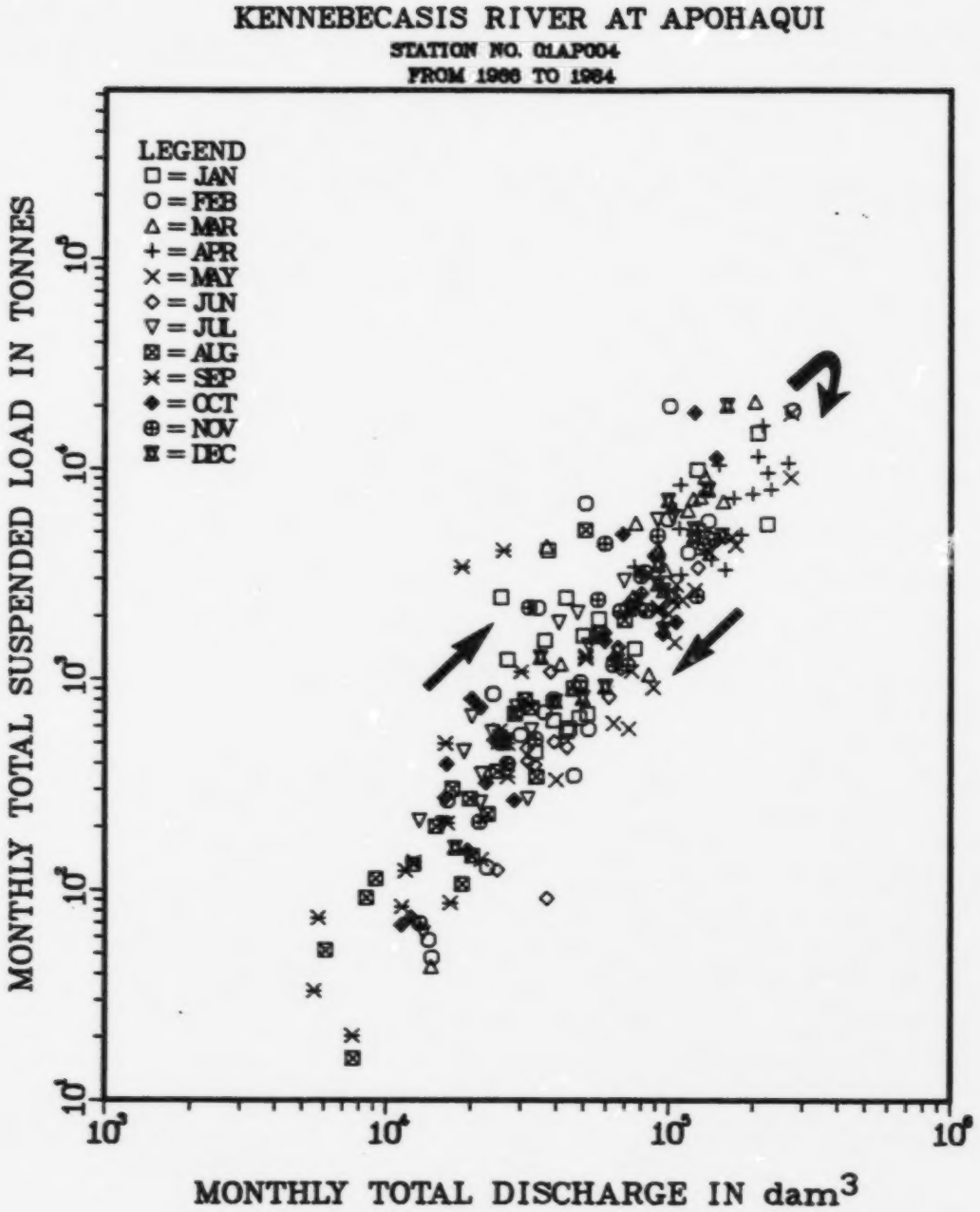


FIGURE 13 RATING RELATIONSHIP FOR MONTHLY TOTAL LOAD VERSUS MONTHLY TOTAL DISCHARGE

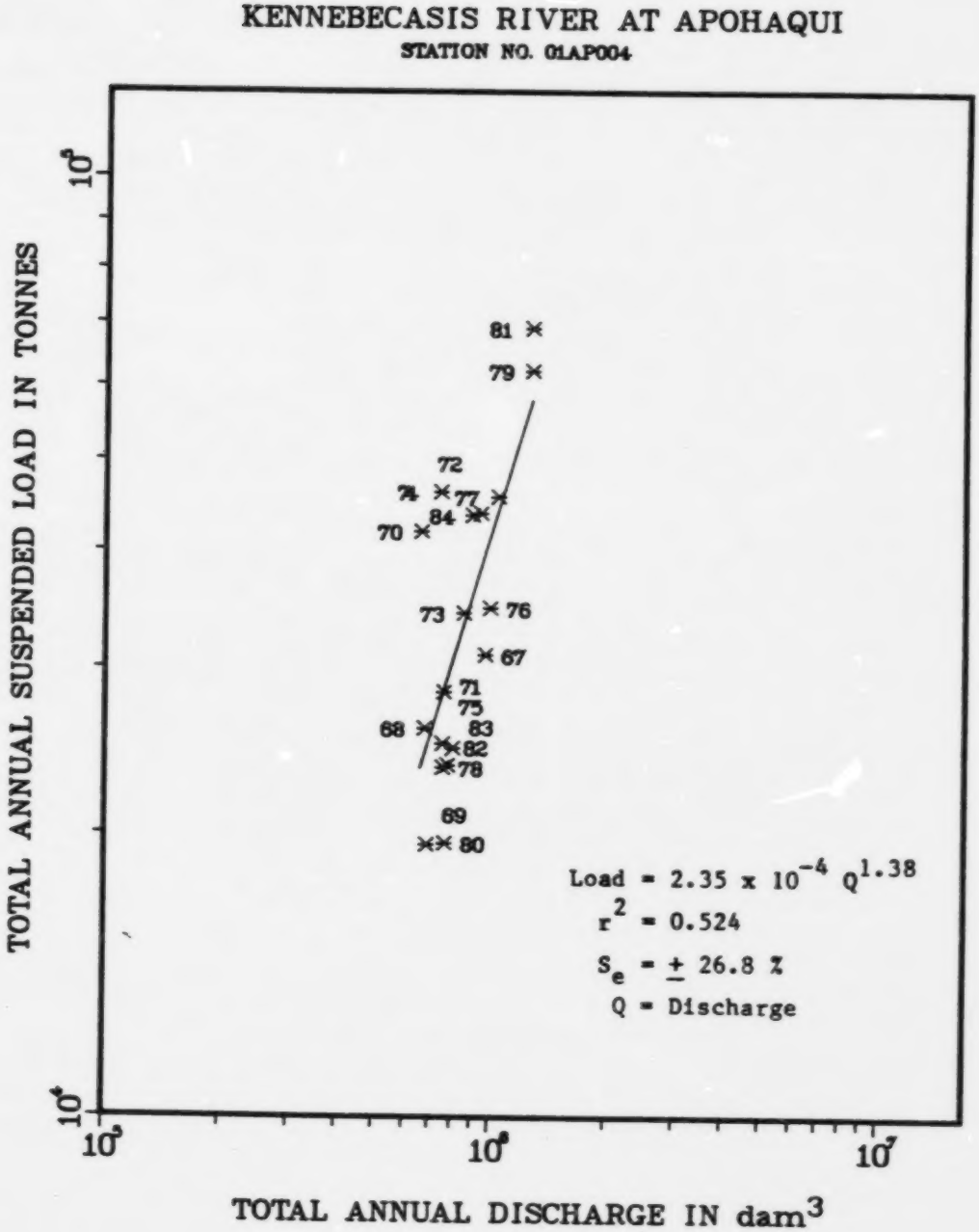


FIGURE 14 ANNUAL FLOW VOLUME VERSUS ANNUAL SUSPENDED SEDIMENT LOAD

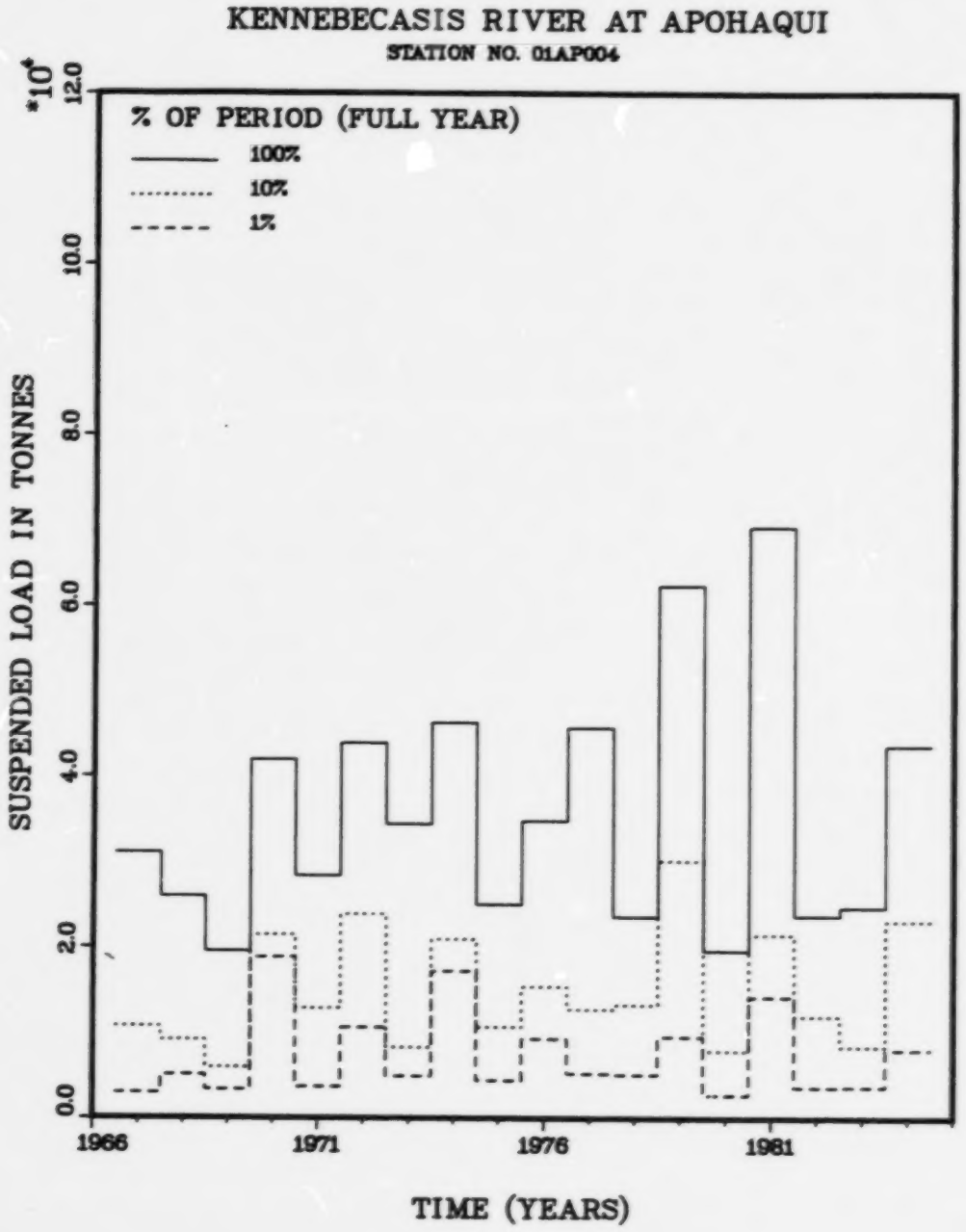


FIGURE 15 CONTRIBUTION OF SHORT DURATION EVENTS TO ANNUAL SEDIMENT LOAD

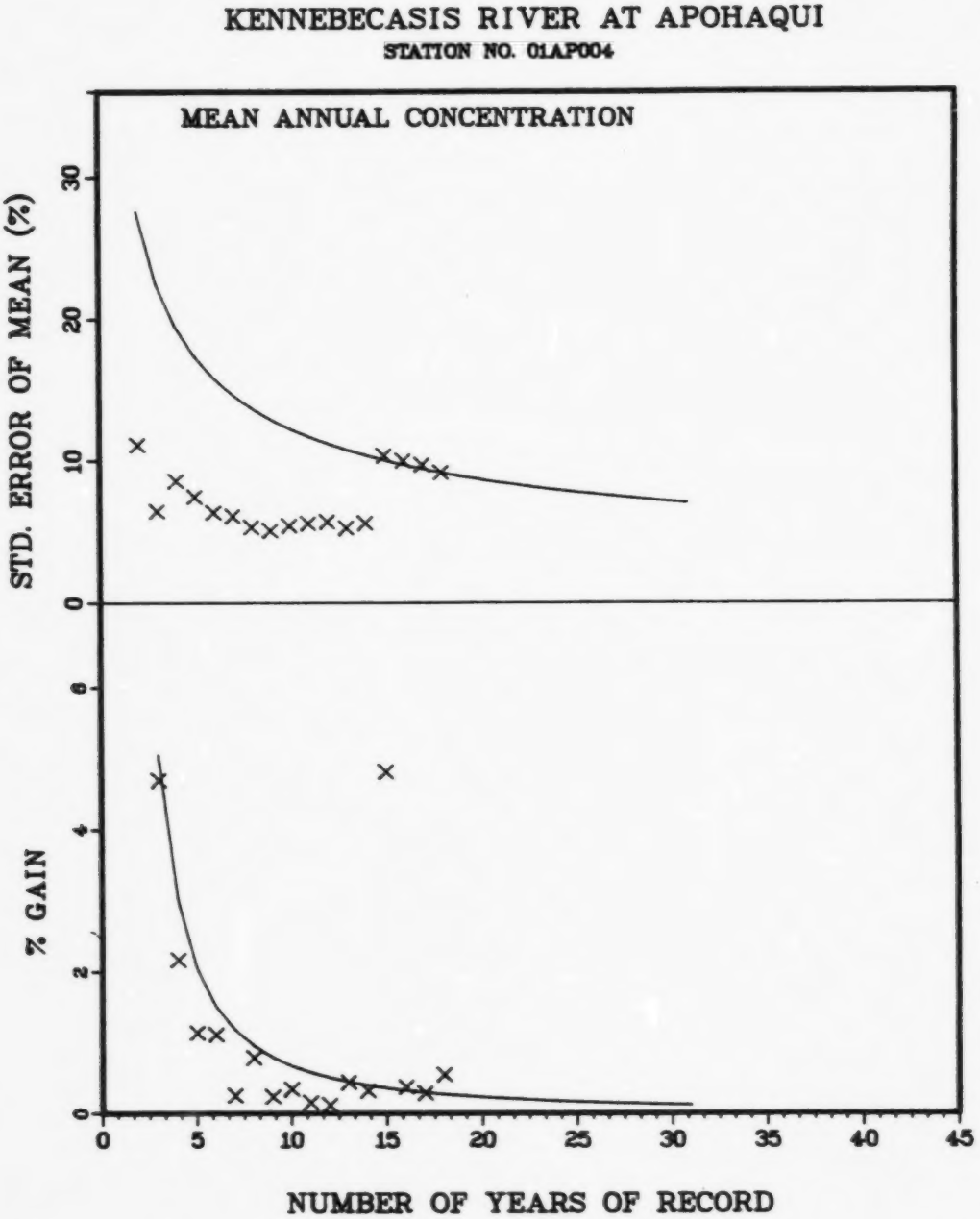


FIGURE 16 RELATION BETWEEN THE STANDARD ERROR OF THE MEAN ANNUAL SUSPENDED SEDIMENT CONCENTRATION AND RECORD LENGTH. THE PERCENTAGE GAIN IN THE STANDARD ERROR OF THE MEAN FOR EACH ADDITIONAL YEAR OF RECORD IS SHOWN IN THE BOTTOM HALF OF THE FIGURE.

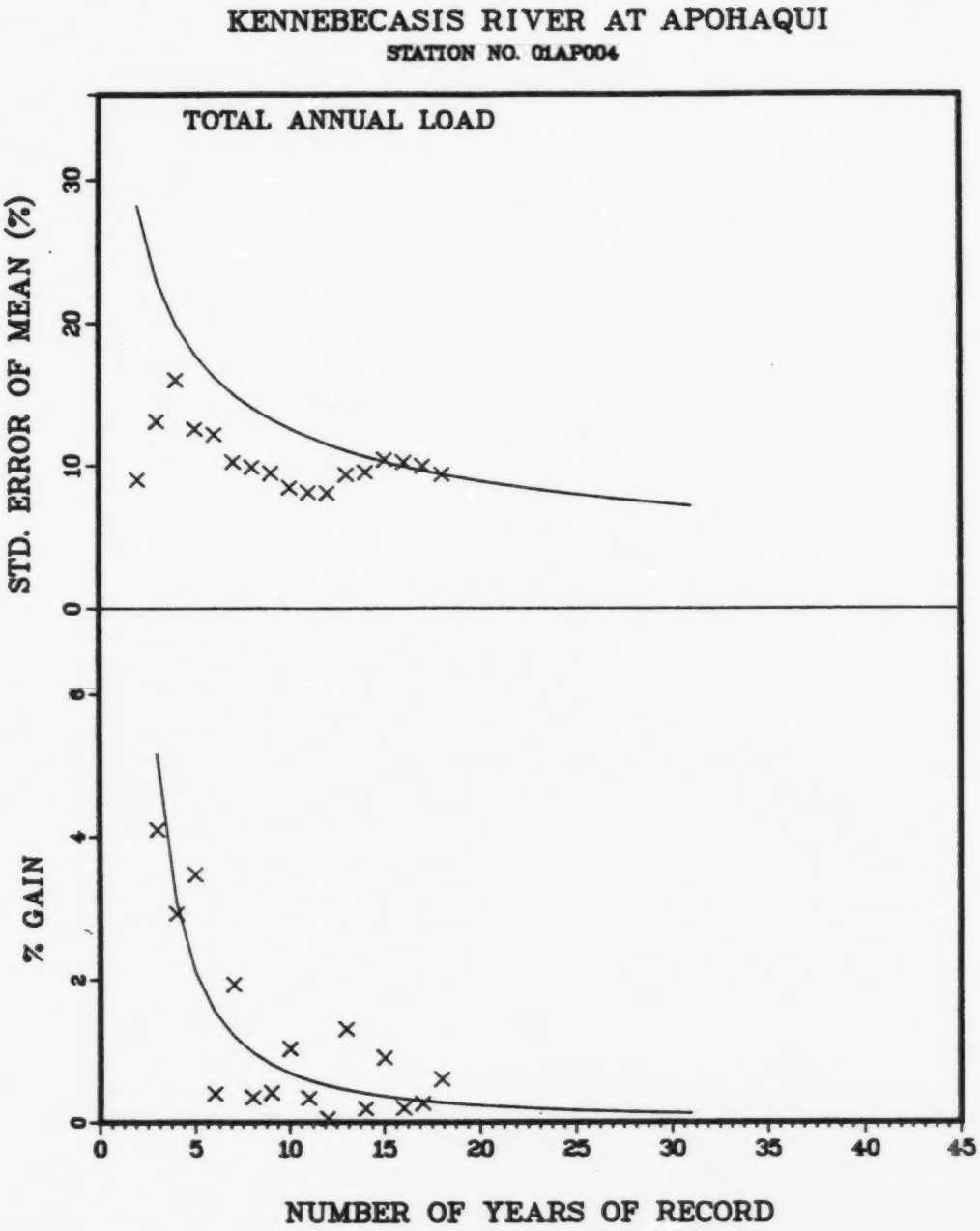


FIGURE 17 RELATION BETWEEN THE STANDARD ERROR OF THE MEAN ANNUAL SUSPENDED SEDIMENT LOAD AND RECORD LENGTH. THE PERCENTAGE GAIN IN THE STANDARD ERROR OF THE MEAN FOR EACH ADDITIONAL YEAR OF RECORD IS SHOWN IN THE BOTTOM HALF OF THE FIGURE.

APPENDIX C
(Photographs)

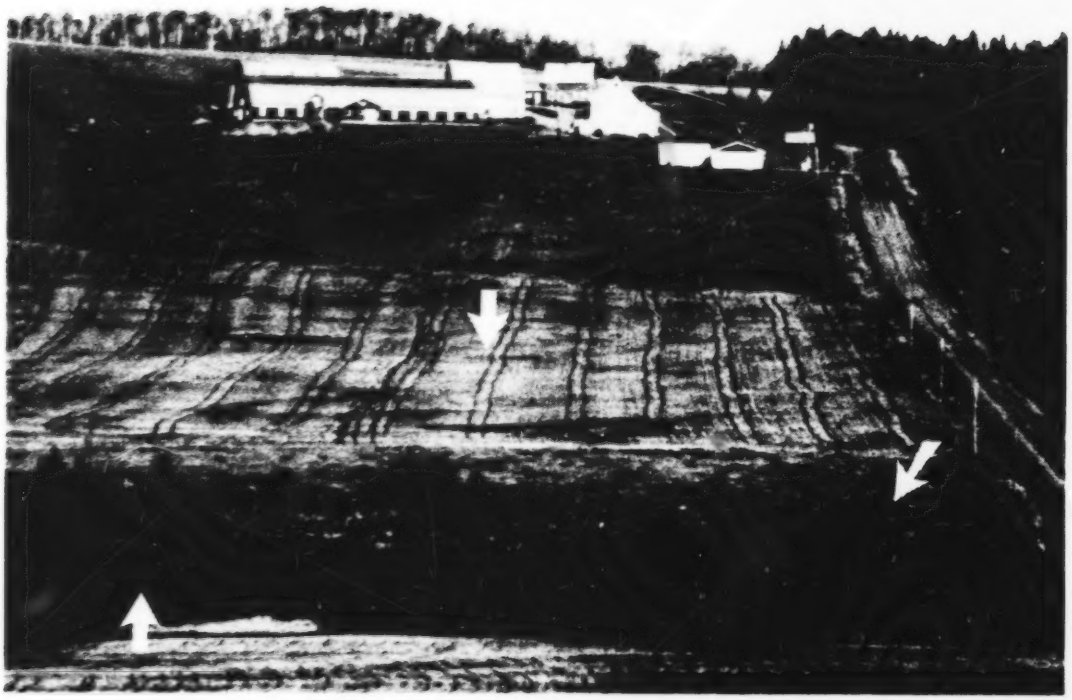


Plate 1. Millstream River near source. Note down-slope orientation of plow furrows and grassed buffer at base of fallow field.

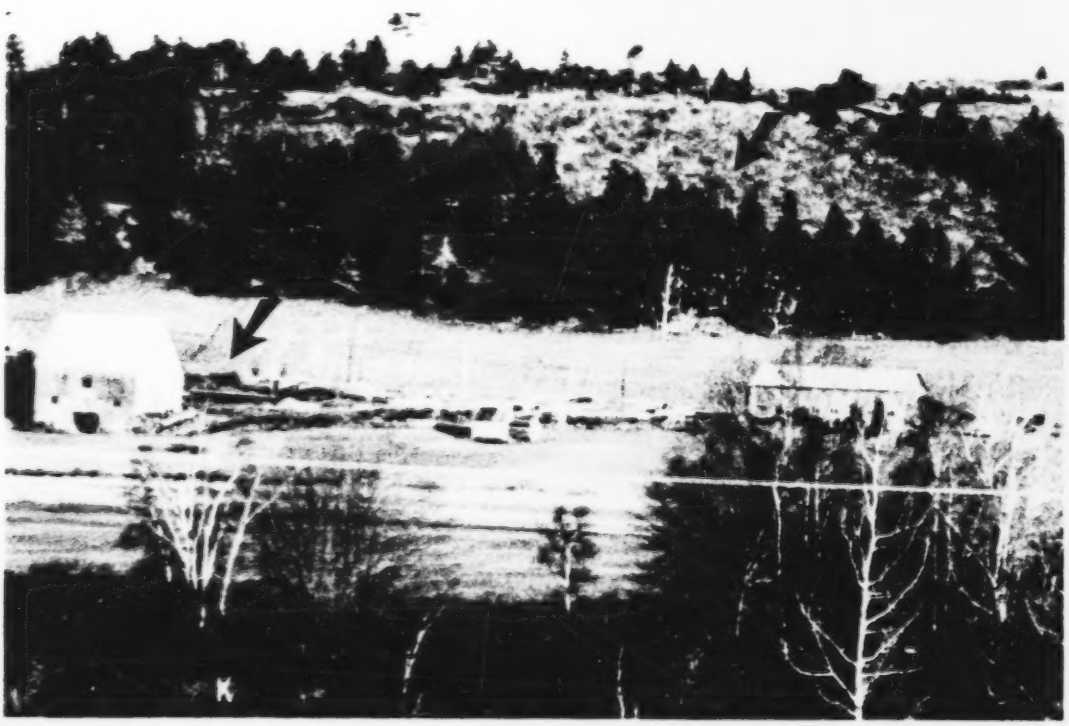


Plate 2. Fox Hill on the north side of the Kennebecasis River. Upper arrow indicates a forest clear cut and the second arrow parallels the plow furrows.

Plate 3. Bank erosion along the meandering Kennebecasis River 2 km west of Plumweseep.

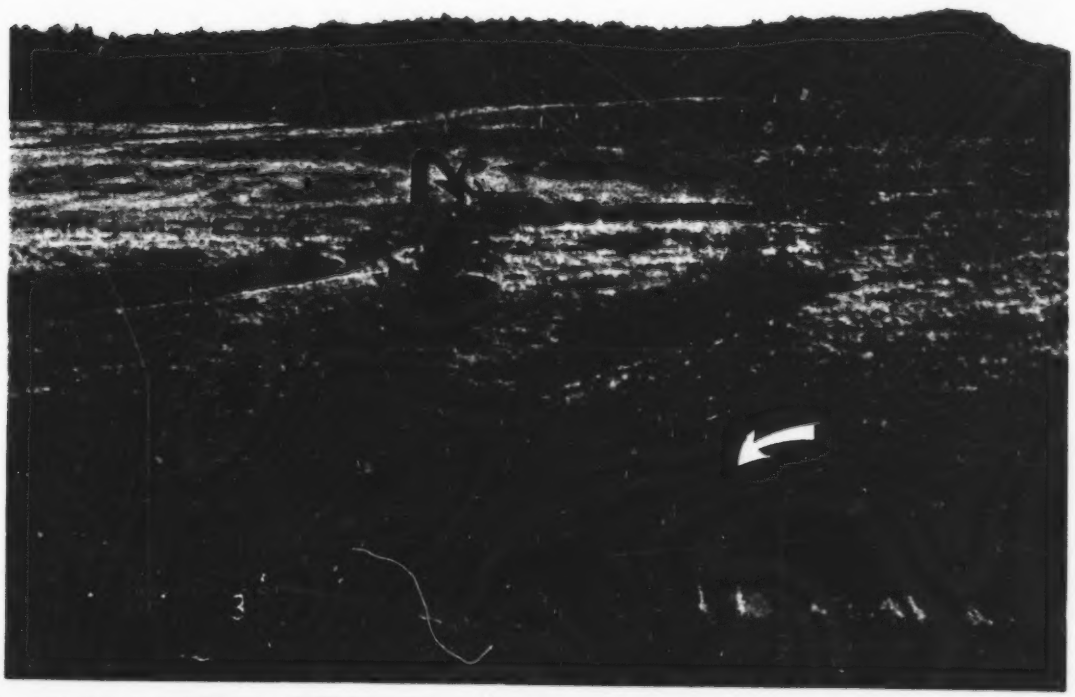


Plate 4. Stream bank erosion on Parsons Brook is occurring on both banks at this point. Note the falling tree.

Plate 5. A grass buffer remains just over the peak of this levee between the upslope grain field and the Kennebecasis River

Plate 6. The modified bank of the Kennebecasis at the Apohaqui Bridge lacks the protective vegetation as found on the opposite side of the river (Plate 5). Drain pipe outflow may create a gully.

Plate 7. Arrow indicates cows grazing on pasture on which spruce trees are encroaching. The "B" in the foreground is located on a jack pine plantation just north of Centreville.

Plate 8. A stream ford used by farm machinery just east of Newtown. Arrow denotes a slope stabilized by a natural vegetation cover.

Plate 9. A landfill site between the junction of Highways 2 and 111 and the Kennebecasis River marked by the covered bridge (top left).

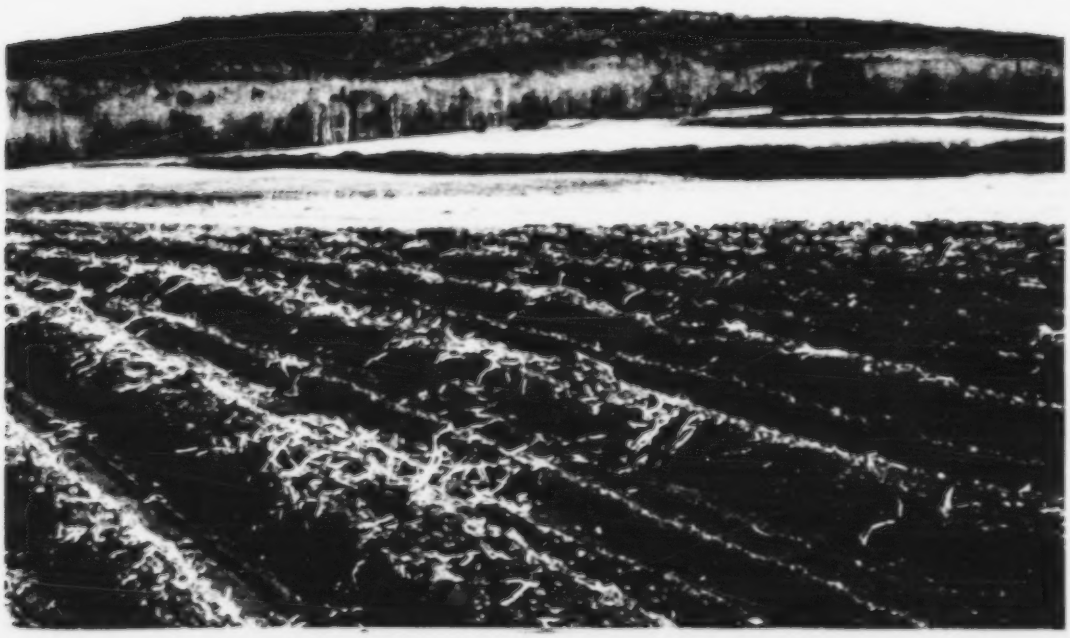


Plate 10. Harvested potatoe field between Parsons Brook and the community of New Line Road. Risk of soil loss from this site is high as furrows run downslope.

Plate 11. The grass cover on the rolling topography, viewed from the west side of the Millstream River, stabilizes the slopes.